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RESEARCH STATUS ON EFFECTS OF LAND APPLICATION OF ANIMAL WASTES

KANSAS STATE UNIVERSITY

PREPARED FOR
ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY

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The primary purpose of this report was to review the literature and analyze research needs on the effects of land application of animal waste. An additional purpose was to assemble published information on application guidelines for animal waste. Included in this report are information on the characteristics of waste, effects of waste on soil and water near application sites, application rates, application techniques, and research needs. This report is organized into six main topics: (1), climate, waste, and soil classification; (2), waste composition; (3), effect of waste on the environment; (4) application rates based on waste constituents; (5) application techniques; and (6) research needs. The climate, waste, and soil classification systems were developed to allow comparison of the effects of animal waste applications on land in various parts of the country. The composition of the waste in each climate was tabulated and values compared. Comparisons between climatic regions were not possible because the large variability within regions. Because of this variability no average composition for a given waste in a given climatic region was possible. The effect of the waste on the environment was measured in terms of the possible final disposition of the waste constituents. These constituents could accumulate in the soil, move to the groundwater, runoff the soil surface, or be taken up by plants. Attempts were made to assemble application guidelines from the various parts of the country.

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RESEARCH STATUS

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EFFECTS OF LAND APPLICATION OF ANIMAL WASTES

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ABSTRACT

The primary purpose of this report was to review the literature and analyze research needs on the effects of land application of animal waste. An additional purpose was to assemble published information on application guidelines for animal waste. Included in this report are information on the characteristics of waste, effects of waste on soil and water near application sites, application rates, application techniques, and research needs.

This report is organized into six main topics: (1), climate, waste, and soil classification; (2), waste composition; (3), effect of waste on the environment; (4), application rates based on waste constituents; (5), application techniques; and (6), research needs. The climate, waste, and soil classification systems were developed to allow comparison of the effects of animal waste applications on land in various parts of the country. The composition of the waste in each climate was tabulated and values compared. Comparisons between climatic regions were not possible because the large variability within regions. Because of this variability no average composition for a given waste in a given climatic region was possible. The effect of the waste on the environment was measured in terms of the possible final disposition of the waste constituents. These constituents could accumulate in the soil, move to the groundwater, runoff the soil surface, or be taken up by plants. Attempts were made to assemble application guidelines from the various parts of the country. It was believed that guidelines should be based on nitrogen content with secondary consideration to accumulation of soluble salts of toxic elements in the soil. In the section on application techniques, various methods of applying the waste to the soil were discussed in terms the layman should be able to understand. In the section on research needs, research needed to develop application guidelines were stressed.

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CONTENTS

		Page
I	Conclusions	1
II	Recommendations	2
III	Introduction	4
IV	Climate, Waste, and Soil Classification Systems	5
V	Waste Composition	10
VI	Effect of Waste on the Environment	29
VII	Application Rates Based on Waste Constituents	49
VIII	Application Techniques	68
IX	Research Needs	72
X	References	75
XI	List of Publications	94
XII	Glossary	95

FIGURES

No.		Page
1	Climatic regions of the United States	6
2	Coarse, medium and fine soil textures in relation to USDA texture classification system	8
3	Schematic summary of factors affecting waste composition and influencing the efficiency of its use on cropland	11
4	Annual manure application rates for resulting low salinity on a medium textured soil	62
5	Annual application rates on nonirrigated land using air-dry manure	66

TABLES

No.		Page
1	The Minimum and Maximum Total Nitrogen Content of Animal Wastes	12
2	The Minimum and Maximum Values Found for Various Animal Waste Constituents	14
3	The Minimum and Maximum Phosphorus Content of Animal Wastes	19
4	The Minimum and Maximum Potassium Content of Animal Wastes	22
5	The Minimum and Maximum Calcium Content of Animal Wastes	23
6	The Minimum and Maximum Magnesium Content of Animal Wastes	24
7	The Minimum and Maximum Sodium Content of Animal Wastes	25
8	The Minimum and Maximum Electrical Conductivity of Animal Wastes	26
9	References on Microorganism Content of Animal Wastes	28
10	References on Soil Properties Affected by Animal Waste Application	35
11	References on Crop Yields Affected by Animal Waste Application	46
12	Manure Application Rates Needed to Insure 50,100 or 200 Pounds of Available Nitrogen per Acre	61
13	Conversion Factors from Dry Weight to Wet Weight	64

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SECTION I

CONCLUSIONS

Animal wastes were found to be extremely variable in their chemical composition. This necessitates the analyses of wastes before application so that rates can be based on nitrogen or salt content of the waste. Variability of the chemical composition and the necessity for chemical analyses before application precludes the use of specific application rates that can be used nationally.

Numerous literature is available on the short term effects of applying animal waste to land, but there appears to be little information available on the long term effects of animal waste on the physical, chemical, and biological properties of the soil. Even fewer publications are available on guidelines which provide methods of calculating animal waste application rates. Because of the lack of data on long term effects on the fate of nutrients and soluble salts added to the soil, it appears that the best and safest application rate is one which supplies just enough nitrogen to maintain optimal plant growth so that the maximum amount of this nutrient can be recycled. Few states have published guidelines on the application of animal waste to land. In areas where guidelines are not available, many agricultural scientists use rule of thumb figures for application rates of animal wastes. In order to avoid errors inherent in rule of thumb figures more experimental data are needed so that guidelines can have a wider applicability.

The research needed to obtain this wide range of applicability is included in the section on Recommendations where specific research needs are enumerated.

SECTION II

RECOMMENDATIONS

One of the basic objectives of this report was to recommend needed research. These recommendations are listed, not in order of their importance, below. Additional research is needed on:

1. The denitrification process as affected by soil temperature, climate, and waste composition. While it is recognized that this process can cause large losses of soil nitrogen into the atmosphere, little is known on how animal waste applications affect this process. In some cases denitrification may account for large errors in underestimating the application rate for a given agronomic system. For this reason, additional research is needed on the denitrification process in soils that have received animal wastes.

2. The fate of soluble salts in manure upon addition to land. In many parts of the United States there is sufficient precipitation to move the soluble salts in manures below the root zone. The ultimate fate and pathways of these salts should be known. Often salts may leach into groundwater by percolation and into surface streams through underground recharge. Insoluble salts may lower the quality of groundwater and surface streams. For this reason, additional research should be done on the fate of inorganic salts upon addition and incorporation to the soil.

3. The long term effect of manure application on crops. There are numerous publications on the effects of animal waste on crop growth. In particular, there was a great deal of research done on fertilization of crops with animal manure during the early part of this century. Additional information on build-up of toxic chemicals in plants such as copper, arsenic, and the accumulation of nitrates in plant material and their effect on foraging livestock is needed. For this reason, some long term studies on the effect of animal waste application to land on crop growth and crop quality should be made.

4. Methods of standardizing animal waste analyses and research reporting. In order to compare research results and establish application rates there must be a standardization of data. Analyses should be expressed on a dry weight basis except possibly for liquids of low solids content (approximately 1% or lower). Data on the location of research by climate and soil characteristics should also be made. Depth of impervious layers, water tables, and other pertinent information should be reported. It is only with these standardizations that meaningful comparisons can be made and guidelines established. Therefore, it is suggested that a standardization of data be established.

5. Nitrogen mineralization and decay rates of manure under different climatic and soil conditions. Because much of the nitrogen contained in animal waste is in an organic form, the decay rate, or the rate at which nitrogen is mineralized in the soil, becomes an important factor in the availability of the nitrogen for plant uptake and for leaching into groundwater. For this reason, more information is needed on mineralization or decay rates in various parts of the country.

There are several areas in which it is felt that additional research is not needed. One of these is additional characterization of beef, dairy, swine, and poultry wastes. The numerous publications on the characterization of these wastes all show extreme variability and, as mentioned in this report, they are difficult to classify by climate. There has been little research done, however, on the characterization of sheep, horse, and fish hatchery wastes. Knowledge of the composition of these wastes must also be known before disposal.

SECTION III

INTRODUCTION

The primary purpose of this project was to review literature and analyze research needs on the effects of land application of animal wastes. An additional purpose was to assemble published information on application guidelines for animal wastes. Included in this report are information on the characteristics of wastes, effects on soil and water near application sites, application rates, application techniques, and research needs. The report was organized into six main topics: (1), climate, waste, and soil classification; (2), waste composition; (3), effect of waste on the environment; (4), application rates based on waste constituents; (5), application techniques; and (6), research needs.

This report was restricted to literature which, in the authors' judgment, best exemplified current research on land application of animal wastes. It was not intended to be a complete literature review of all information on animal waste application. Comprehensive listings of research have been published by Wells (220), Miner et al. (130), and Azevedo and Stout (15). This report was intended to provide a summary of research on land application of animal wastes.

Not all available literature was usable because of the method in which the data were reported. For example, if solid manure application rate and analyses data were reported on a wet weight or "as is" basis without giving the dry weight or solids content, the data were not usable.

The basic approach for this report was to search for a rationale for application rates in terms of climate, soil and waste composition and to determine the research needed to fill the information gaps. Although several regions in the United States have very little information, the amount of animal production in those areas may be too small to justify concern. This document is not a guideline for animal waste application; the intent was that this document be used to point out information needed to develop guidelines for animal waste application.

SECTION IV
CLIMATE, WASTE, AND SOIL CLASSIFICATION SYSTEMS

CLIMATE CLASSIFICATION

Because climate influences the decay rate of organic matter in animal wastes and the accumulation and movement of waste constituents, it was necessary to divide the United States into several climatic classifications. The two basic parameters of the classification system are annual precipitation and temperature, both of which affect the percolation rate of waste constituents through soil, organic matter content, decay rates, and such processes as denitrification and salt accumulation.

Temperature, precipitation, and evaporation have been used by Shuyler et al. (178) to classify the United States into 12 climatic regions. Those same 12 climatic regions were used in this report (Fig. 1). The regional divisions are based on temperature, annual precipitation, and moisture deficit (annual lake evaporation minus annual precipitation). Although this climatic classification was originally intended as an aid to feedlot site selection, it serves the purpose of this report and avoids creating another system.

As an example of this classification system, Minnesota is in region 1 while North Dakota is in region 5 (Fig. 1). Although they both have approximately the same annual temperature patterns, North Dakota has a higher annual moisture deficit which could, for example, cause manure in North Dakota to have characteristics different from manure in Minnesota. It could also mean that there is less water available in North Dakota to remove soluble salts from the soil profile after land application.

WASTE CLASSIFICATION

The physical and chemical properties of animal wastes can influence the effect of land application on the environment. For example, liquid runoff from beef feedlots generally has lower fiber content than solid manure. Because of the fiber in the solid manure, it will be less likely to adversely affect the physical properties of the soil after land application.

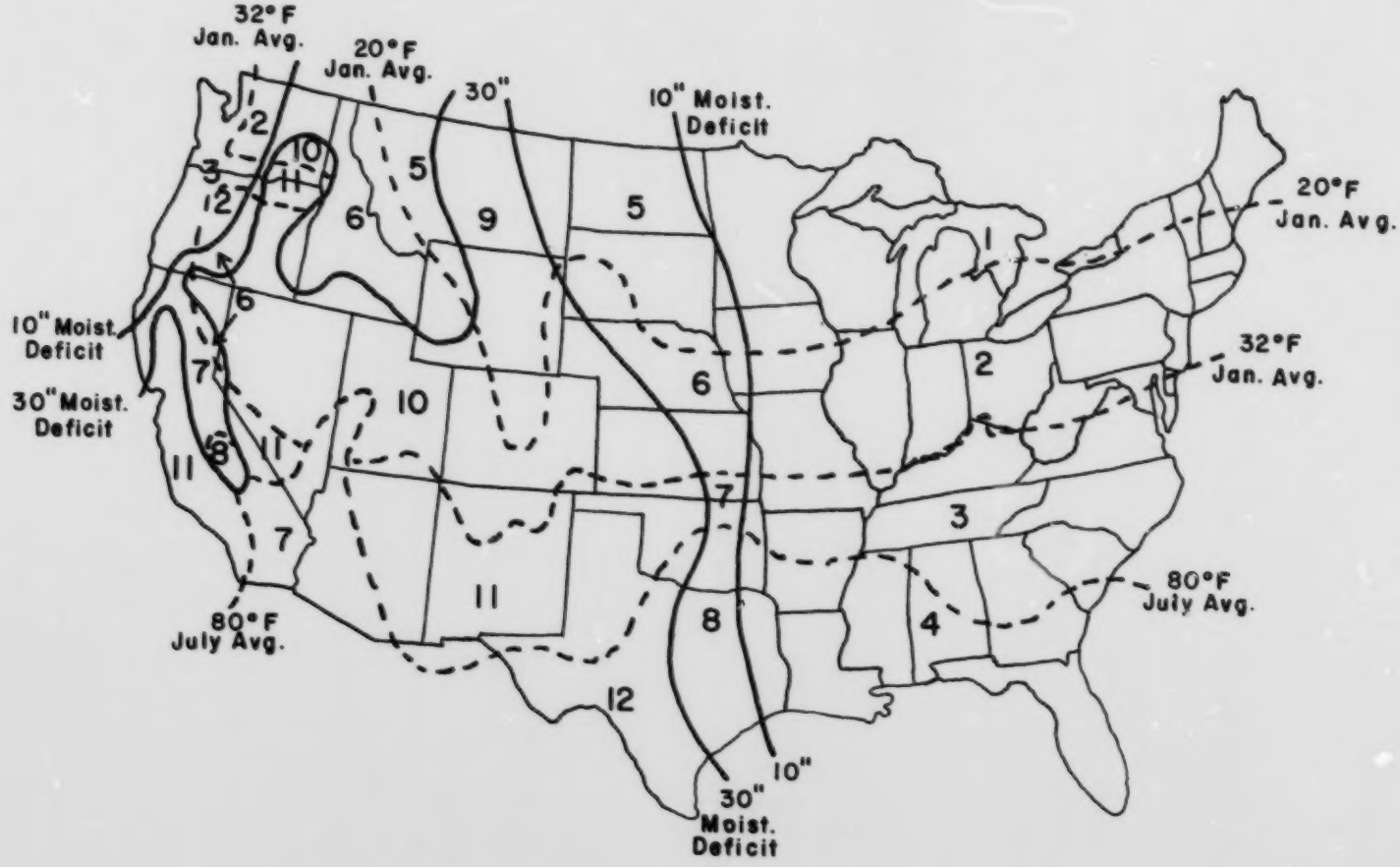

Figure 1. Climatic regions of the United States. Adapted from Shuvler et al. (178).

SOIL CLASSIFICATION

No less than the climate and the type of waste, the soil also can influence the rate of biological decay, chemical reactions, and water movement. The influence of the soil type on animal waste application is related to its water holding capacity, water permeability, and other textural properties. For example, more accumulation of inorganic salts would be expected in a fine-textured soil with high exchange capacity and low water permeability than in a coarse-textured soil with low exchange capacity and high water permeability.

In this report we have classified soils into three broad categories: coarse-textured soils (sands, loamy sands, and light sandy loams); medium-textured soils (heavy sandy loams, loams, silt loams, light clay loams, light silty clay loams, and silts); and fine-textured soils (heavy clay loams, heavy silty clay loams, silty clay loams, sandy clays, and clays). For the convenience of the reader, the classifications are shown superimposed on the USDA textural triangle in Fig. 2. The classes are enclosed by dashed lines.

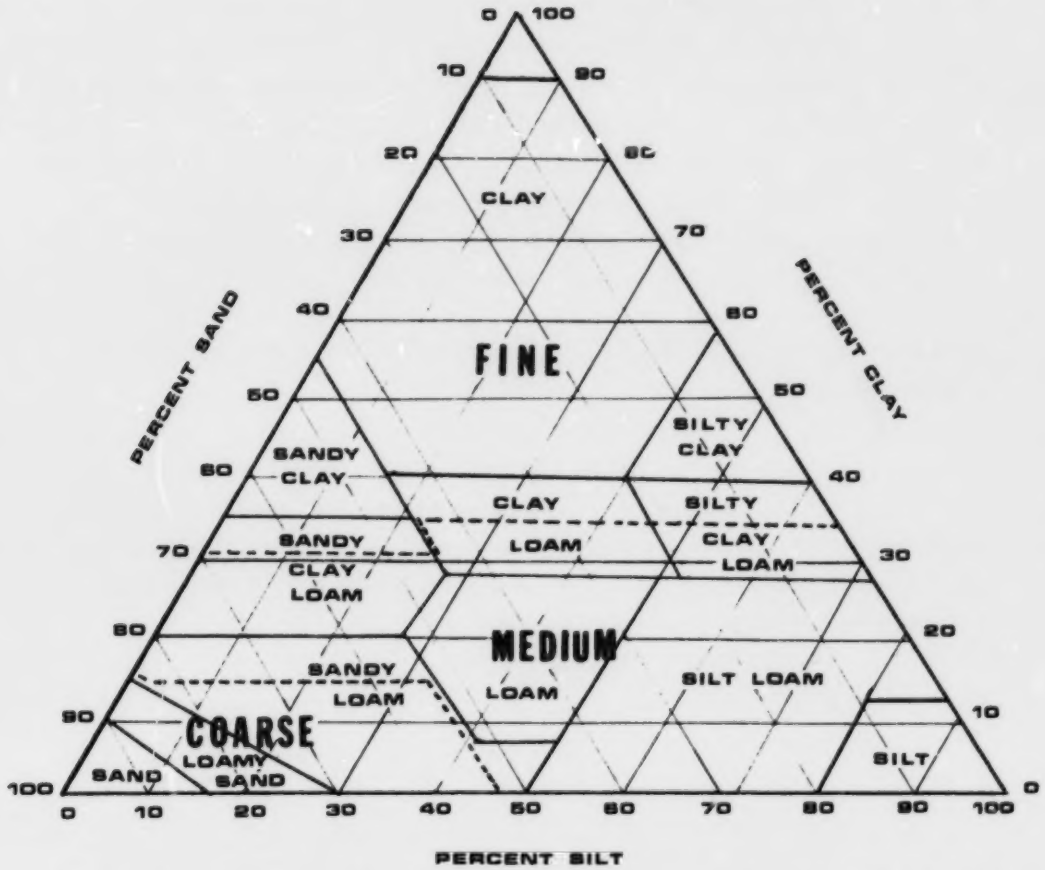

Figure 2. Coarse, medium and fine soil textures (outlined by dashed lines) in relation to USDA texture classification system. Adapted from USDA Handbook No. 18 (181).

SECTION V

WASTE COMPOSITION

INTRODUCTION

A prediction of the effects of animal waste application on soil properties and plant growth requires a foreknowledge of the composition of the waste material. Only if the concentrations of the constituents in the waste are known can one estimate reactions such as solute movement in the soil and plant nutrient availability or toxicity.

Waste composition data in the literature were compiled by recording all usable data and classifying them by climatic region, species, and type of waste. To eliminate variation due to water content, data were recorded on a dry-weight basis (DWB). Data reported on a wet-weight basis (WWB) were converted to DWB when possible. If the reference used the WWB and did not state the dry matter or total solids content, the data were not used. Approximately 25% of the data found were not usable for that reason. An exception was made for the beef runoff waste because practically all characterization data found for that particular classification were given on a WWB.

Tables 1 to 8 contain the final compilation of data for each constituent according to climatic region and waste characterization. Only the highest and lowest values found are included in the tables. Mean values are not given because of the lack of accuracy obtained when data (some of which themselves are mean values) from divergent sources are averaged, and because the tremendous variability in waste composition makes land application calculations based on mean values subject to large errors. Generally the value of these tables will be to illustrate that the range in composition for all constituents is so great that analysis of the specific waste is an absolute necessity before land application.

The composition tables contain many blank spaces because no data were found for those particular combinations of climatic regions and waste types. While it may appear at first glance that little characterization

work has been done on a national scale, it can be seen from the 1969 Census of Agriculture (209) that some climatic regions contain too little livestock production to justify land application research.

If the waste composition data were constant from one animal production site to the next, then the task of determining application rates would be less complicated. Unfortunately, there are several factors that can influence waste composition, and these factors work together to make the composition of waste extremely variable. Climate, species, ration and management are the four general factors that can influence waste characteristics. A summary of these factors is shown in Figure 3. These factors will be considered according to how they affect the concentration of each constituent.

NITROGEN

Range of Nitrogen Concentrations by Animal and Climate

Table 1 contains the minimum and maximum percent total nitrogen content of the 16 animal waste types in the 12 regions. No consistent trends attributable to climatic regions are evident. Data are not available for regions 5, 8, 9, and 12.

Considerable variability in the data exists within most classifications. Solid poultry manure has been considered to have the highest nitrogen content of the four species, but Table 1 shows it to have minimum values as low as, or lower than, the other three species. The digested beef, swine, and poultry slurries generally had high nitrogen contents which under certain circumstances might be due to the gaseous loss of non-nitrogen solids, which increased nitrogen on a dry-weight basis.

The large differences between the low and high values in most classifications point out the potential errors that could be made if an average nitrogen concentration were used in making application rate calculations. For example, assume that the average nitrogen content of solid poultry waste in region 1 was found to be 5%. If a poultry facility were producing solid waste with a nitrogen content of 11% (the maximum value found for that region), an application rate based on the 5% average value would be 2.2 times larger than what it would be if the actual 11%

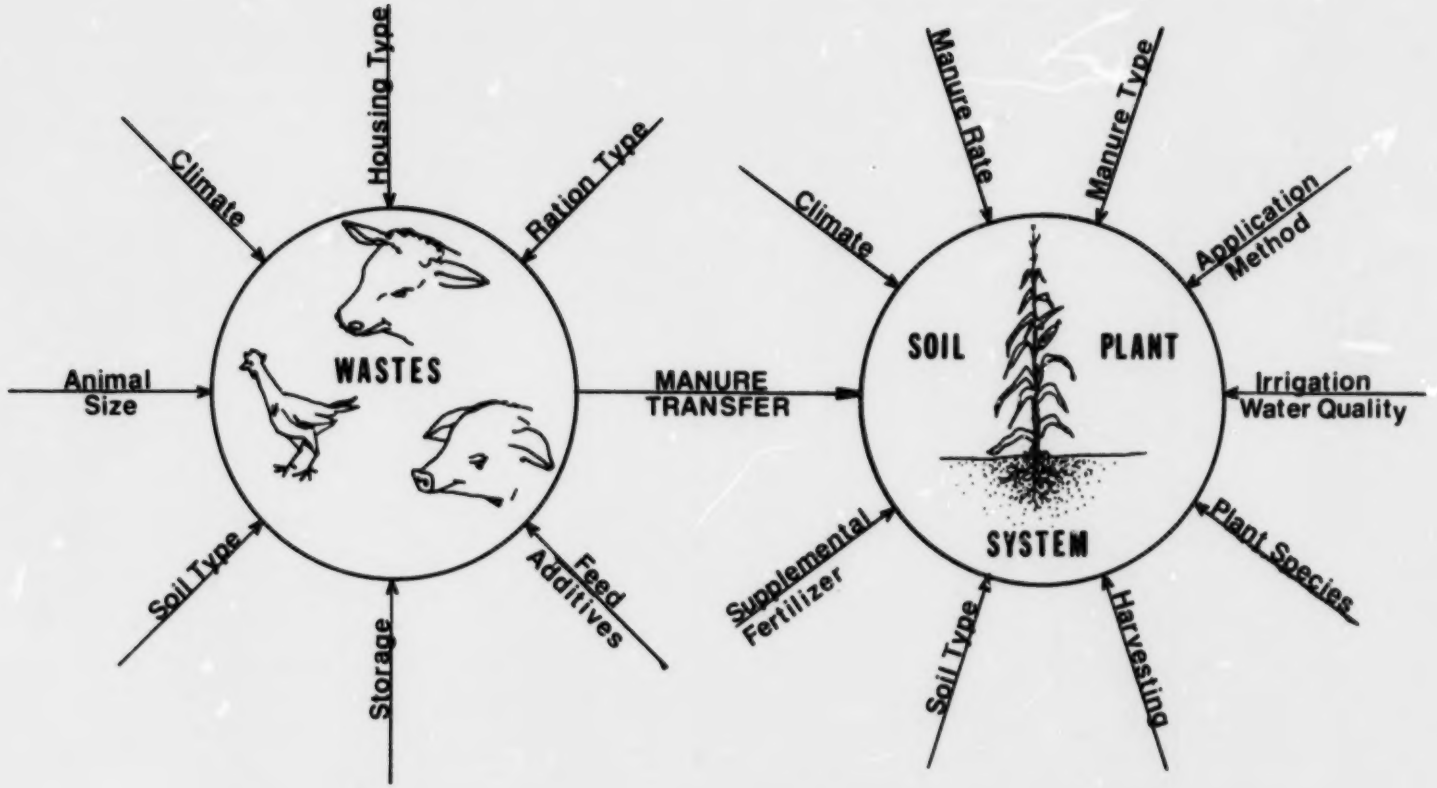

Figure 3. Schematic summary of factors affecting waste composition and influencing the efficiency of its use on cropland.

Table 1. THE MINIMUM AND MAXIMUM TOTAL NITROGEN CONTENT OF ANIMAL WASTES.[a]
(percent)

Species and Type of Waste	Climatic Region[b]								
	1	2	3	4	6	7	10	11	None[c]
Beef									
Solid	2.5-4.2	2.0-3.7	--	--	--	2.0	.60-2.0	2.8-3.6	2.2-4.9
Runoff	--	.0022-.048	--	--	.0011-.86	--	--	--	--
Slurry (D)[d]	--	11	--	--	--	--	--	--	--
Slurry (U)[d]	7.5-9.0	4.4	--	--	1.9	--	--	4.8	3.3
Dairy									
Solid	1.5-3.7	2.5	--	--	--	--	--	1.8-2.0	2.7-3.9
Runoff	--	4.8	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--	--
Slurry (U)	1.8-5.1	2.4-3.6	--	--	--	--	--	4.8	2.4
Swine									
Solid	--	2.8	--	--	--	--	--	--	2.0-7.5
Runoff	--	4.8	.40	--	--	--	--	--	--
Slurry (D)	--	8.8-12	--	--	--	--	--	--	--
Slurry (U)	9.8-19	11	6.3	--	--	--	--	--	3.4-17
Poultry									
Solid	2.7-11	--	1.1-6.7	1.1-6.7	--	--	--	--	3.4-7.8
Runoff	--	--	--	--	--	--	--	--	--
Slurry (D)	--	2.2-7.8	--	--	--	--	--	--	--
Slurry (U)	--	7.4	--	--	--	--	--	--	--

[a] Beef runoff data on wet weight basis, all other on a dry weight basis, single values indicate only one reference found.

[b] No data were found for regions 5, 8, 9, and 12.

[c] Climatic region not given in reference.

[d] D refers to digested and U to undigested slurries.

References used: beef, 12, 27, 42, 44, 61, 107, 112, 113, 114, 122, 144, 158, 167, 175, 189, 196, 198, 203, 207, 214, 216; dairy, 8, 17, 19, 37, 51, 60, 113, 118, 128, 144, 158, 160, 189, 190, 192, 203; swine, 44, 73, 113, 144, 189, 191, 198, 203; and poultry, 25, 63, 99, 138, 142, 144, 172, 177, 182, 189, 198, 203, 223.

value were used. If the actual value were 2.7% nitrogen (the lowest value found for that region) then the application rate based on the average value would be 0.54 times smaller than what it would be if the actual 2.7% value were used.

Those examples represent the extremes in possible errors, but they also illustrate what could happen if average values were used. The method used in calculating average values will, of course, affect their reliability. An average of multiple samples from one animal production site would be less subject to error than one obtained from multiple samples taken from a region, if that average value from the production site were used for calculating application rates for that site only. The factors influencing waste composition are more likely to be consistent within a single production site than between different production sites.

The ammonium-nitrogen and nitrate-nitrogen content of animal wastes were also found to be extremely variable, with no trend evident because of climatic region. The data were combined over all regions and were presented according to waste type in Table 2.

Factors Affecting Nitrogen Concentration

Climate - Total confinement livestock housing in which the waste is stored until spread on the land, will produce wastes that are generally unaffected by climate. Climate can influence nitrogen content of manure produced from livestock operations located outside or that involve waste storage outside.

Climate can affect the nitrogen composition of animal wastes by several methods. If the waste is stored where it is exposed to rainfall, then the natural precipitation can dilute the waste if it is liquid or remove soluble nitrogen compounds by leaching if the waste is solid. Those two processes proceed at greater rates in regions of higher rainfall.

In climatic regions that are characterized by hot, drying conditions, waste material can lose large quantities of nitrogen by ammonia

Table 2. THE MINIMUM AND MAXIMUM VALUES FOUND FOR VARIOUS ANIMAL WASTE CONSTITUENTS.[a]

Species and Type of Waste	BOD_5 (gm/gm)	COD (gm/gm)	Fe (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	B (mg/kg)	NO_3-N (mg/kg)	NH_4-N (%)	Cl (%)
Beef										
Solid	23	15-100	195-33100	25-401	24-1630	1.5-177	15-137	0-1800	.62-1.1	1.1-2.7
Runoff	--	.13-7.7	1.3-4170	.04-415	.1-146	.05-28	--	0-280	.0002-.20	.034-.07
Slurry (D)	--	--	--	--	--	--	--	--	--	--
Slurry (U)	38	120-390	660-1280	65-320	64-224	14-45	25-38	0-38	.33-5.7	2.9-4.3
Dairy										
Solid	17	78-98	190-1760	8.51-79.6	110-131	20.3-21.0	49.3-59.8	0-5.0	.62-.87	1.0-2.8
Runoff	--	--	--	--	--	--	--	--	.05	--
Slurry (D)	--	--	--	--	--	--	--	--	--	--
Slurry (U)	13-34	99-210	354-1330	93.2-135	94.2-110	21-24.8	55.9-73	0-49	1.0-1.8	.88-1.2
Swine										
Solid	33	95-108	1100	--	--	--	--	--	--	--
Runoff	2.0	6.0	--	--	--	10	--	1000	.20	--
Slurry (D)	--	--	--	--	--	116-189	--	.04-.18	.02-6.9	--
Slurry (U)	30-90	88-220	600-1800	380-1800	200-380	100-1400	78-270	0-43	3.8-7.6	4.4
Poultry										
Solid	27	90	65-8890	65-309	135-525	3.7-1000	15-60	0	7.2	--
Runoff	--	--	--	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	0-1300	.38-5.2	--
Slurry (U)	38	130	--	--	--	--	--	6.3	--	--

[a]Beef runoff data on wet weight basis, all other on a dry weight basis, single values indicate only one reference found.

References used: beef, 42, 44, 112, 113, 114, 122, 144, 158, 167, 175, 196, 203, 214, 216, 217; dairy, 19, 37, 51, 59, 113, 128, 144, 158, 190, 192, 203, 204; swine, 43, 44, 72, 73, 113, 144, 191, 203; and poultry, 47, 99, 142, 144, 172, 177, 203.

volatilization. It has been estimated that under Southern California conditions, about 50% of the nitrogen in dairy manure is lost to the air by ammonia volatilization and denitrification between the time of excretion and the time manure is incorporated into the soil (7). Adriano et al. (6) also obtained nitrogen losses approaching 50%.

The effect of climate on nitrogen content is not seen in Tables 1 and 2 because ration and management are so dominant that they obscure the climate effect.

Species - Poultry and swine are generally considered to produce waste highest in nitrogen. Inspection of Table 1, however, shows that the nitrogen content of wastes from all species can range from relatively low to high values. Even though the fresh excrement from some species may be higher in nitrogen than that from other species, factors such as climate and management can create such variability that the waste when finally applied does not resemble the original in nitrogen content.

Analyses of poultry wastes in Georgia has shown broiler manure to be generally higher in nitrogen than hen manure. There were, however, large variations in the composition of both types of manure (152, 154). A study in Michigan by Adriano (4) revealed no meaningful relation between the type of ration and beef manure composition.

Ration - No research was found that dealt with the effect of ration on the nitrogen content of animal waste. Because nitrogen is one of the most expensive components of animal feeds, rations generally contain the minimal amounts of nitrogen that will give optimal performance. For that reason, ration will not likely be used as a method for controlling nitrogen content of waste.

Management - The method of waste handling and storage between the time of excretion and application can have a major effect on the quantity of nitrogen contained in that waste. Nitrogen content, more than any other constituent, is sensitive to management. Nitrogen can be lost by ammonia volatilization, leaching of soluble nitrogen compounds, dilution, and microbial utilization.

Several researchers have shown that up to 50% of the nitrogen excreted by cattle can be lost through ammonia volatilization (7, 126, 174). Most of the ammonia volatilized came from the urine fraction of the waste. In poultry manure, up to 60% of the nitrogen can be lost by ammonia volatilization (47, 151).

Prediction of the magnitude of nitrogen loss by ammonia volatilization is difficult because ammonia volatilization is affected by both weather fluctuations and how the waste is handled. If the waste is to be stored in the open and exposed to drying conditions, then some nitrogen loss should be expected. In Michigan, Adriano (4) found lower nitrogen contents in beef manure from open lots than from total confinement housing systems. In this study, manures from open lots had about half as much nitrogen than manures from total confinement systems.

Loss of nitrogen to the atmosphere before land application will lower the amount of nitrogen entering the soil system and lower the potential for groundwater contamination. The ammonia volatilization does represent, however, a loss of a valuable plant nutrient that should be minimized if the waste is to be used as a fertilizer source. When the waste is sampled for nitrogen analysis, the sampling should be done as nearly as possible to the time of application so that the sample will represent the nitrogen content of the waste applied to the soil.

If a waste is exposed to rainfall during storage, its nitrogen content will be lowered. Leaching of solid waste can remove much of the water soluble nitrogen, which can comprise as much as 50 to 60% of the total nitrogen in steer manure (174). Simple dilution of liquid waste lowers its nitrogen concentration.

Degradation processes that occur naturally in storage lagoons or that occur under controlled conditions in treatment systems can alter the nitrogen content of the liquid waste. Up to 80% of the nitrogen in swine waste can be removed by treatment in an oxidation ditch (180). Digestion processes can also have the opposite effect and raise the nitrogen content of wastes on a dry weight basis as solid matter is converted to water and gases.

HEAVY METALS AND TRACE ELEMENTS

Range of Heavy Metals and Trace Elements Concentration by Animal and Climate

The heavy metals and trace elements that have received attention in animal waste application research are iron, zinc, manganese, copper, and boron. Table 2 contains the range of concentrations found in the waste types combined over all climatic regions. Elements other than those five were mentioned in the literature, but not frequently enough to justify further discussion here.

There were large differences between the low and high values for all elements in most classifications. No trends by waste type are evident. The very high iron concentrations found in several classifications could be explained by soil, which is high in iron being mixed with the waste after excretion or cattle being fed iron salts.

Factors Affecting Heavy Metal and Trace Element Concentrations

Climate - No research was found that reported the effects of climate on the heavy metal or trace element content of animal wastes.

Species, Ration - Swine rations can contain copper as a feed additive. Hogs will excrete, mostly in the manure, approximately 80% of the copper they consume. Animals fed rations higher in copper will produce wastes that contain correspondingly greater amounts of copper (13, 57, 73, 74).

Management - There was little definitive research found that dealt with the effect of management on the heavy metal or trace element content of animal wastes. Because most are multivalent cations, their solubilities in aqueous solutions are generally lower than that of the monovalent cations such as sodium and potassium. Management practices that separate the solid portion of liquid wastes should, therefore, segregate these elements into the solid portion. It has been estimated that 85% of the copper entering a swine-waste lagoon is tied up with the solid matter at the bottom of the lagoon because it does not appear in the lagoon effluent (72, 73).

Table 3. THE MINIMUM AND MAXIMUM TOTAL PHOSPHORUS CONTENT OF ANIMAL WASTES.[a]
(percent)

Species and Type of Waste	Climatic Region[b]								
	1	2	3	4	6	7	10	11	None[c]
Beef									
Solid	.69-.89	.11-1.4	--	--	--[d]	.27	.31-.80	.60-.71	.28-1.6
Runoff	--	.32-.72[d]	--	--	.95-520[d]	--	--	--	--
Slurry (D)	--	3.2	--	--	--	--	--	--	--
Slurry (U)	2.0-2.3	.69-1.5	--	--	.52	--	--	1.2	1.4
Dairy									
Solid	.41-1.6	.56	--	--	--	--	--	0.7	.48-.7
Runoff	--	2.4	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--	--
Slurry (U)	.54-.87	.43-1.2	--	--	--	--	--	--	.87
Swine									
Solid	--	1.1	--	--	--	--	--	--	.56-2.5
Runoff	--	1.2	0.1	--	--	--	--	--	--
Slurry (D)	--	3.1-6.4	--	--	--	--	--	--	--
Slurry (U)	2.8	3.6	2.1	--	--	--	--	--	1.2-3.7
Poultry									
Solid	--	1.4-2.6	.38-6.3	1.4-6.3	--	--	--	--	1.5-2.8
Runoff	--	--	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--	--
Slurry (U)	--	1.5	--	--	--	--	--	--	2.3

[a] Beef runoff data on wet weight basis, all other data on a dry weight basis, single values indicate only one reference found.
[b] No data were found for regions 5, 8, 9, and 12.
[c] Climatic region not given in reference.
[d] Values X 10^{-3} (i.e. 0.00032-0.00072 and 0.00095-0.520).

References used: beef, 4, 12, 27, 42, 44, 61, 79, 107, 112, 113, 114, 122, 144, 158, 167, 189, 196, 198, 203, 207, 214, 216; dairy, 8, 17, 19, 37, 51, 59, 60, 113, 118, 128, 144, 158, 189, 190, 192, 203; swine, 44, 73, 113, 144, 189, 191, 198, 203; and poultry, 25, 47, 63, 142, 144, 172, 177, 182, 189, 198, 203, 223.

BIOLOGICAL OXYGEN DEMAND (BOD_5), CHEMICAL OXYGEN DEMAND (COD), AND TOTAL ORGANIC CARBON (TOC)

Range of BOD_5, COD, and TOC Concentrations by Animal and Climate

Table 2 contains the minimum and maximum BOD_5 and COD data combined over all climatic regions. Too little TOC data were found to justify its inclusion. No trends related to waste type or climatic region are apparent in the BOD_5 and COD data. The sparsity of data found for these two constituents makes it difficult to analyze their variability.

Factors Affecting BOD_5, COD, and TOC Concentrations

Climate, Species, and Ration - No research was found on the effects of climate, species, or ration on the BOD_5 or COD of animal wastes.

Management - The BOD_5 and COD of animal wastes are reduced through digestion processes. Improvement of the quality of liquid wastes by digestion is desirable if the waste should mistakenly be discharged directly into surface waters or if runoff occurs from the application site. The effect of lowering the BOD_5 and COD on the land application properties of the waste has not been established.

INORGANIC SALTS

Range of Inorganic Salts Concentration by Animal and Climate

Tables 4, 5, 6, 7, and 8 contain the potassium, calcium, magnesium, sodium, and electrical conductivity (EC) data, respectively, for the various waste-climate classifications. The EC of a solution is an estimation of the total soluble salt content. The large range between the minimum and maximum values in most classifications shows that inorganic salt concentration can vary widely. Examination of data provides no trends related to type of waste or climate classification. The variation within most classifications obscures any differences that might exist between classifications.

Factors Affecting Inorganic Salts Concentration

Climate - Solid wastes that are exposed to the leaching action of rainfall will lose some inorganic salts to the leachate. The leaching volume is

one factor that determines the quantity of salts lost, so wastes stored in the open in climates with relatively high rainfall are likely to contain fewer salts.

Species - Swine and poultry wastes contain more potassium than beef and dairy wastes, according to Table 4. No other species differences are evident in the inorganic salt data.

Ration - The quantity of inorganic salt fed to an animal will affect the amounts excreted. Sodium chloride or "table salt" is added as a supplement to most livestock rations and some beef producers provide additional sodium chloride in free choice salt licks. The salinity of the waste will increase with increasing amounts of sodium chloride fed to beef cattle (85, 110), while other work has shown no benefit, measured by daily gain and feed efficiency, in adding salt supplement to the ration of beef cattle (98).

Vegetative plant parts have a higher concentration of potassium than does the grain. Animals being fed a roughage ration will consequently excrete more potassium than if the same animals were being fed a high-concentrate ration.

Management - Volatilization losses of inorganic salts have not been reported. Alteration of the inorganic-salt concentrations of animal wastes after excretion is usually caused by leaching or dilution with water.

Of the four inorganic salts (cations) being considered here, potassium and sodium are the most soluble in water because they are not bound in the structure of organic molecules and because they are less attracted to colloidal particles than are calcium and magnesium. Also calcium and magnesium have a greater tendency to form inorganic precipitates than either sodium or potassium. Consequently, management practices that allow leaching of wastes with water will allow removal of larger portions of the sodium and potassium salts than of the calcium and magnesium salts.

Table 4. THE MINIMUM AND MAXIMUM POTASSIUM CONTENT OF ANIMAL WASTES.[a]
(percent)

Species and Type of Waste	Climatic Region[b]								
	1	2	3	4	6	7	10	11	None[c]
Beef									
Solid	1.5-1.9	.41-4.0	--	--	.053-1.0	1.1	.30-1.8	1.9-3.8	.92-3.6
Runoff	.018-.048	--	--	--	.0097-.19	.11-.19	.026-.20	.048	--
Slurry (D)	--	9.6	--	--	--	--	--	--	--
Slurry (U)	.24-3.1	.44-3.4	--	--	1.7	--	--	3.3	.79
Dairy									
Solid	1.4-3.3	2.2	--	--	--	--	--	2.0-3.4	2.4-2.6
Runoff	--	4.8	--	--	6.9	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--	--
Slurry (U)	1.9-5.0	2.0-3.6	--	--	--	--	--	--	2.7
Swine									
Solid	--	1.9	--	--	--	--	--	--	1.5-4.9
Runoff	--	3.6	0.2	--	--	--	--	--	--
Slurry (D)	--	2.9-8.3	--	--	--	--	--	--	--
Slurry (U)	3.3	4.8	3.3	--	--	--	--	--	1.0-4.5
Poultry									
Solid	--	2.4-5.2	.73-4.8	1.4-4.8	--	--	--	--	1.5-2.4
Runoff	--	--	--	--	--	--	--	--	--
Slurry (D)	--	2.5-4.3	--	--	--	--	--	--	--
Slurry (U)	--	--	--	--	--	--	--	--	--

[a] Beef runoff data on wet weight basis, all other on a dry weight basis, single values indicate only one reference found.
[b] No data were found for regions 5, 8, 9, and 12.
[c] Climatic region not given in reference.

References used: beef, 12, 27, 42, 44, 61, 79, 107, 112, 113, 114, 122, 144, 158, 167, 175, 189, 196, 198, 203, 207, 214, 216, 217; dairy, 8, 17, 19, 37, 51, 59, 60, 113, 118, 128, 144, 158, 189, 190, 192, 203, 204; swine, 44, 73, 113, 144, 189, 191, 198, 203; and poultry, 25, 47, 63, 99, 142, 144, 172, 177, 182, 189, 198, 223.

Table 5. THE MINIMUM AND MAXIMUM CALCIUM CONTENT OF ANIMAL WASTES.[a]
(percent)

Species and Type of Waste	Climatic Region[b]							
	1	2	3	6	7	10	11	None[c]
Beef								
Solid	.68-1.8	.67-9.3	--	.03-.48	2.8	.36-1.4	1.9	.60
Runoff	--	--	--	.0075-.35	.031-.052	.011-.062	.010	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	3.0-3.5	.60-1.0	--	--	--	--	2.7	--
Dairy								
Solid	2.[illegible]-2.5	--	--	--	--	--	3.2	1.3
Runoff	--	--	--	2.8	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	1.6-2.4	2.2	--	--	--	--	--	--
Swine								
Solid	--	--	--	--	--	--	--	2.3
Runoff	--	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	3.5	--	--	--	--	--	--	.24-.36
Poultry								
Solid	--	1.7-11	.62-5.[illegible]	--	--	--	--	--
Runoff	--	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	--	--	--	--	--	--	--	--

[a] Beef runoff data on wet weight basis, all other on a dry weight basis, single values indicate only one reference found.
[b] No data were found for regions 4, 5, 8, 9, and 12.
[c] Climatic region not given in reference.

References used: beef, 4, 27, 44, 112, 113, 122, 158, 175, 207, 214, 216, 217; dairy, 19, 37, 59, 113, 118, 128, 158, 204; swine, 44, 73, 113; and poultry, 25, 47, 142, 172, 177, 223.

Table 6. THE MINIMUM AND MAXIMUM MAGNESIUM CONTENT OF ANIMAL WASTES.[a]
(percent)

Species and Type of Waste	Climatic Region[b]							
	1	2	3	6	7	10	11	None[c]
Beef								
Solid	.44-.65	.33-2.62	--	.032-.32	1.5	.30-.50	1.0	.20
Runoff	--	--	--	.0049-.235	.015-.017	.0098-.024	.0064	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	1.0-1.1	.48-.63	--	--	--	--	1.3	--
Dairy								
Solid	.36-.90	--	--	--	--	--	.73	.52
Runoff	--	--	--	.60	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	.68-.91	.25	--	--	--	--	--	--
Swine								
Solid	--	--	--	--	--	--	--	--
Runoff	--	--	.04	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	1.4	--	.63	--	--	--	--	.03-.12
Poultry								
Solid	--	.47-1.0	.06-1.7	--	--	--	--	--
Runoff	--	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	--	--	--	--	--	--	--	--

[a] Beef runoff data on wet weight basis, all other on a dry weight basis, single values indicate only one reference found.
[b] No data were found for regions 4, 5, 8, 9, and 12.
[c] Climatic region not given in reference.

References used: beef, 4, 44, 112, 113, 122, 158, 175, 207, 214, 216, 217; dairy, 19, 37, 59, 113, 118, 128, 158; swine, 44, 73, 113; and poultry, 25, 47, 142, 172, 177, 223.

Table 7. THE MINIMUM AND MAXIMUM SODIUM CONTENT OF ANIMAL WASTES.[a]
(percent)

Species and Type of Waste	Climatic Region[b]							
	1	2	3	6	7	10	11	None[c]
Beef								
Solid	.26-.76	.05-.69	--	.055-.17	2.8	.15-.49	.76-1.9	1.3
Runoff	--	--	--	.0090-.28	.065-.13	.011-.17	.032	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	1.6-1.9	.09-.24	--	--	--	--	1.9	.12
Dariy								
Solid	.35-.46	--	--	--	--	--	.90	--
Runoff	--	--	--	11	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	.34-.42	.092-.31	--	--	--	--	--	1.3
Swine								
Solid	--	--	--	--	--	--	--	--
Runoff	--	--	.04	--	--	--	--	--
Slurry (D)	--	.60-2.9	--	--	--	--	--	--
Slurry (U)	2.0	--	.63	--	--	--	--	1.6
Poultry								
Solid	--	.66-.89	--	--	--	--	--	--
Runoff	--	--	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--	--	--
Slurry (U)	--	--	--	--	--	--	--	--

[a] Beef runoff data on wet weight basis, all other on a dry weight basis, single values indicate only one reference found.
[b] No data were found for regions 4, 5, 8, 9, and 12.
[c] Climatic region not given in reference.

References used: beef, 4, 27, 44, 107, 112, 122, 158, 167, 175, 203, 207, 214, 216, 217; dairy, 19, 128, 158, 190, 192, 203, 204; swine, 44, 73, 191, 203; and poultry, 172, 177.

Table 8. THE MINIMUM AND MAXIMUM ELECTRICAL CONDUCTIVITY OF ANIMAL WASTES.[a]
(mmho/cm)

Species and Type of Waste	Climatic Region[b]					
	1	2	6	7	10	11
Beef						
Solid	1.3-2.3	1.1-12	--	--	--	--
Runoff	--	--	0.9-20	8.6-13	1.6-13	1.4
Slurry (D)	--	--	--	--	--	--
Slurry (U)	3.6	5.4-6.9	4.5	--	--	--
Dariy						
Solid	1.0-2.3	--	--	--	--	--
Runoff	--	--	13	--	--	--
Slurry (D)	--	--	--	--	--	--
Slurry (U)	1.8-3.7	--	--	--	--	--
Swine						
Solid	--	--	--	--	--	--
Runoff	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--
Slurry (U)	5.6	--	--	--	--	--
Poultry						
Solid	--	--	--	--	--	--
Runoff	--	--	--	--	--	--
Slurry (D)	--	--	--	--	--	--
Slurry (U)	--	--	--	--	--	--

[a] Single values indicate only one reference found.
[b] No data were found for regions 3, 4, 5, 8, 9, and 12.

References used: beef, 4, 27, 44, 112, 114, 175, 196, 217; dairy, 128, 204; swine, 44.

MICROORGANISMS

Range of Microorganisms Concentration by Animal and Climate

Because several methods of reporting the microorganism content of animal wastes were found in the literature, only the references are given here (Table 9).

Factors Affecting Microorganisms Concentration

Climate, Ration - No research was found that dealt with the effect of climate or ration on the microorganism content of animal wastes.

Species - Reference should be made to the literature cited in Table 9 for microorganism analyses data on various animal species.

Management - Some microorganisms, such as fecal coliform, are naturally occuring and are found in all animal manures. Management of the animals for disease prevention and control will, therefore, be an important factor affecting the content of animal wastes.

Survival of microorganisms in animal wastes is quite variable and depends upon both the disease organisms and the method of waste handling. An excellent review of the literature dealing with survival of microorganisms in animal wastes has been prepared by Azevedo and Stout (15).

MEDICINAL

An excellent review of research dealing with fecal residues resulting from the feeding of hormones, antibiotics, and other medicinals to animals has been published (11). Although it has been shown that a large portion of medicinals fed passes through the animal, it appears at this time that the relatively small amounts of chemicals involved will not affect the land application properties of the waste.

Table 9. REFERENCES ON MICROORGANISM CONTENT OF ANIMAL WASTES.[a]

Species and Type of Waste	Microorganisms			
	Coliform	Fecal Coliform	Bacteria	Salmonella
Beef				
Solid	46	81	--	--
Runoff	133	133	--	132
Dairy				
Solid	46	--	115	--
Slurry (U)	--	40	115	40
Swine				
Solid	46	72	164	--
Slurry (U)	--	--	73	--
Poultry				
Solid	46	--	47	89

[a] Numbers indicate references in Bibliography.

SECTION VI

EFFECT OF WASTE ON THE ENVIRONMENT

EFFECT OF LAND APPLICATION ON SOIL PROPERTIES

Physical Properties

Infiltration Rate - The rate at which water moves into the surface of the soil is called the infiltration rate, measured in length per unit time such as centimeters per hour. Applications of animal waste will usually increase the infiltration rate of a soil, but some work has shown a decrease in infiltration rate after waste applications.

The organic matter content of the animal waste is largely responsible for increasing soil infiltration rates. Zwerman et al. (232) found that a single application of 13.5 t/ha of solid dairy manure increased soil infiltration rate by 27% in a continuous corn culture. Manure did not increase infiltration significantly when the same rate of manure application was used on four crop rotations, three of which included legume crops. It was suggested that because legume crops add organic matter to soil, the effect of manure on infiltration was not measureable.

Swader and Stewart (195) applied up to 112 wet t/ha of solid beef manure to a soil in Texas and found that the infiltration rate of the soil was not affected significantly by the feedlot manure, although a trend in increased infiltration rate was noted. Infiltration into the B horizon of the soil, however, was increased by all application rates. The B horizon was thought to be the soil layer most restrictive to water movement.

In a laboratory study, Travis et al. (204) measured the infiltration rate of lagoon water into soil columns. Infiltration into all columns ceased before 2 pore volumes (a pore volume is the volume of liquid equivalent to the pore space in the column) of leachate were collected. Because a prepared water solution containing only the inorganic salt caused similar results, it was suggested that increased concentrations of the monovalent cations sodium, potassium, and ammonium dispersed the soil

aggregates, which stopped the movement of water through the columns.

Manges and Eisenhauer (101) studied the effects of beef-feedlot-lagoon water on the infiltration rate of a furrow-irrigated soil. When the infiltration of well water and lagoon water were added together, it was found that total infiltration was reduced by intermediate lagoon water application rates (10.2 and 20.3 cm/yr) compared to plots receiving well water only, lower application rates (5.1 cm/yr), or high application rates (40.6 cm/yr). Beef-feedlot-lagoon water contains high concentrations of monovalent cations (Na^+, K^+, NH_4^+) and does not contain the large amount of organic matter contained in solid waste. In a related study, Manges et al. (102) found an opposite trend in the infiltration rate of irrigation water into soils that had received applications of beef-feedlot manure. Infiltration rates increased with manure application rates up to treatments ranging from 93 to 269 t/ha/yr, but decreased with higher manure application rates.

Hydraulic Conductivity - Hydraulic conductivity is a measure of the rate of water flow in the soil. Hydraulic conductivities have been increased or decreased by applications of animal wastes.

Azevedo and Stout (15) measured the hydraulic conductivity of three soil mixtures of 5% chicken manure, 5% cattle manure, and 5% fibers from dairy cattle manure. It was found that chicken and cattle manures decreased hydraulic conductivity, while the 5% fibers mixture increased hydraulic conductivity compared to the untreated soil. It was concluded that the fiber content of animal manures is the most important constituent controlling soil hydraulic conductivity after waste applications.

In further work, Azevedo and Stout (15) investigated the effects of cattle manure on the hydraulic conductivity of soils that had been altered previously to known concentrations of exchangeable sodium. At all levels of exchangeable sodium, beef manure improved the hydraulic conductivity of the soils studied. The positive effects on hydraulic conductivity offset the deleterious effects of increased concentrations of monovalent cations.

In a study by Cross et al. (35), three rates of beef-cattle manure of up to 583 dry t/ha were applied to a Nebraska soil. No significant differences in hydraulic conductivity were found. Concern was expressed, however, that the large amounts of the monovalent cations sodium and potassium could lead to deterioration of the physical properties of soil.

In another Nebraska study, Hinrichs et al. (69), applied beef-feedlot-lagoon water to a silty clay loam soil for 2 years at rates of up to 5 cm per week. The hydraulic conductivity of the soils receiving the lagoon water was lowered significantly. Hydraulic conductivity measurements taken after winter rainfall were close to pretreatment values, indicating that leaching improved the soil hydraulic conductivity.

Powers (155) studied the effects of beef-feedlot-lagoon water and beef-feedlot manure on the hydraulic conductivity of the surface 10 cm of an irrigated soil. On plots that had received the solid manure, it was found that application rates of up to 179 dry t/ha/yr over a four-year period did not affect hydraulic conductivity significantly, while application rates of from 359 to 717 dry t/ha/yr generally increased soil hydraulic conductivity. The intermediate rates of lagoon water (10.2 and 20.3 cm/yr) reduced soil hydraulic conductivity compared to plots receiving no treatment, lower treatments (5.1 cm/yr), or plots receiving higher treatments (40.6 cm/yr). Manges and Eisenhauer (101) measured infiltration rates on the lagoon water plots and found the same trend. Accumulations of monovalent cations resulting in the dispersion of soil aggregates was suggested as the reason for the lowered hydraulic conductivity in the soils that had received the lagoon water.

Bulk density - The bulk density of a soil is its mass per unit volume. Soils with lower bulk densities are usually easier to till, have a higher water holding capacity, and are more easily drained. Applications of animal wastes to soils decrease the bulk density of soils because of a dilution effect resulting from the mixing of the added organic matter with the more dense mineral fraction of soils. How much the bulk density is lowered depends on the amount of waste applied, the organic matter content of the waste, and the original soil bulk density. Because a large portion of the organic matter of liquid wastes has been removed before application, the effect of liquid wastes on soil bulk density will generally be less than

that of solid wastes.

Several researchers have measured decreased bulk densities in soils treated with animal waste. Evans et al. (44) found that solid beef and manure slurry decreased the bulk density of the 0 to 15 cm layer of the soil they studied, and that the solid beef manure decreased the bulk density in the 15 to 30 cm layer. Unger and Stewart (208) applied solid beef-feedlot manure to a clay loam soil and found that the two highest rates of manure, 134 and 268 t/ha, decreased the bulk density relative to the control soil and to soils that received two lower rates of manure applications. It was suggested by Unger and Stewart (208) that improved soil aggregation and organic matter contributed to the lower bulk density. Applications of 269 and 583 t/ha of beef manure were found by Cross et al. (35) to decrease soil bulk density.

Solid animal waste will not always decrease the bulk density of soils. Swader and Stewart (195) could not detect any differences in the bulk density of soils treated with beef-feedlot manure. Broiler litter had no effect on soil bulk density in a study by Hileman (67). Runoff from a beef feedlot, a material that is low in organic matter, did not lower the bulk density of a silty clay loam soil in a study by Hinrichs et al. (69).

Water holding capacity - In some of the earlier research on the effects of manure applications on the fertility of soils, it was found that yield increases could not be accounted for entirely by improved levels of nutrients in the soil. It has been suggested that this unexplained yield increase could have been due to improved soil physical properties, and specifically to improved water holding capacity. Several researchers (14, 55, 56, 71) found that because of improved water availability manure treated plots had larger yield increases in dry years than in wet years.

There have been successful attempts at measuring increased available water in soils treated with animal wastes. Gingrich (50) showed that manure increased the available water capacity of some soils. Salter (173) measured little variance in available water capacity, but found manure decreased the force with which the water was held in the soil (soil

moisture tension). This would have increased water availability and improved crop yields.

Swader and Stewart (195) investigated the effects of beef-feedlot manure on the A and B horizons (first two layers) of a Texas soil. Application rates of up to 112 t/ha of manure had no effect on the water holding capacity of either horizon. The organic matter content of the soil, however, was not significantly increased.

Aggregate stability - The resistance to disintegration of soil aggregates upon wetting is called its aggregate stability. Animal wastes act to improve aggregate stability through the addition of soil organic matter. Organic matter helps to bind soil particles together and improve physical properties by encouraging a greater proportion of the larger aggregates to remain intact after wetting. Other beneficial soil physical properties, such as percent pore space, infiltration rates, and hydraulic conductivity tend to increase along with increases in aggregate stability.

Aggregate stability is commonly measured by the wet sieve method, in which the percentage of different size particles are determined after wetting. Unger and Stewart (208) found that application of 134 and 268 t/ha of beef-feedlot manure to a clay loam soil decreased the proportion of aggregates smaller than 0.25 mm and increased the proportion of aggregates greater than 4.0 mm. Similar results were found by Cross et al. (35) when 269 t/ha of solid beef manure were applied to a Nebraska soil. The 269 t/ha rate mixed with the top 10 cm increased the water stability of the soil aggregates.

Chemical Properties

Most of the early research involving the effects of animal wastes on soil chemical properties dealt with the availability of the major plant nutrients, nitrogen, phosphorus, and potassium. It was repeatedly shown that soil fertility was improved by the addition of these nutrients to the soil. When soil is used as a medium for waste application, however, amounts of plant nutrients added are frequently in excess of what can be used by the growing crop. More recently, researchers have begun to study the possible deleterious effects of accumulations and movements of these plant nutrients

on the environment, while continuing to recognize that land application remains the most efficient method of recycling these nutrients.

To review all the published data pertaining to the effects of animal wastes on soil chemical properties would be beyond the scope of this publication. Listed in Table 10 are references that have measured specific soil chemical characteristics after land application. The effects on chemical constituents most often emphasized in those references will be summarized in the following discussion.

Accumulation and movement of waste constituents Nitrogen - Nitrogen seems to have received the most attention in research dealing with the effects of land application on the environment. Nitrogen in either inorganic or organic forms can be transformed by the microbial population in the soil into nitrate nitrogen. Because nitrate is an anion, it is not absorbed on soil particles, does not form insoluble precipitates and is easily leachable through soil. Movement of nitrate nitrogen into ground or surface waters creates an environmental hazard because it, along with other nutrients, can cause algal blooms in surface waters. The United States Department of HEW standard for nitrate-nitrogen concentration in drinking waters is less than 10 parts per million. Consequently, there has been interest in measuring the accumulation and movement of nitrogen, particularly nitrate nitrogen, in soil after land application of wastes.

Several researchers have measured increases in total soil nitrogen after heavy applications of solid feedlot wastes (61, 108, 138, 184, 216) and dairy-manure slurry (40). Large amounts of native soil nitrogen are present in most soils; a mineral soil with a 0.1% nitrogen content on a dry-weight basis will contain approximately 4200 kg of nitrogen in the top 30 cm of one hectare. Applications of animal waste will generally not increase the measureable amount of total nitrogen in soil with time unless large quantities are continuously applied.

Numerous researchers have measured the accumulation and movement of nitrate nitrogen in soils after animal waste applications (Table 10). The production of nitrate nitrogen in soil is a complicated process (18), but even though the factors that influence this process are understood, it is very hard to predict in a given situation the magnitude of nitrate-

Table 10. REFERENCES ON SOIL PROPERTIES AFFECTED BY ANIMAL WASTE APPLICATION.[a]

Constituent	Species			
	Beef	Dairy	Swine	Poultry
Total Nitrogen	61, 108, 138, 216	8, 40	22, 23, 72	70
Nitrate Nitrogen	44, 51, 93, 97, 106, 107, 108, 109, 122, 138, 184, 186, 188, 216, 217, 230	7, 8, 19, 83, 94, 105, 128, 190, 192	44, 51, 191	21, 29, 47, 66, 70, 99, 172, 185
Nitrite Nitrogen	44, 51, 107, 186, 216	128	44, 51	47, 99
Ammonium Nitrogen	44, 51, 106, 107, 108, 138, 184, 186, 204, 216	7, 128, 190	44, 51, 191	66, 70, 77, 91, 99, 179, 185
Trace Elements (Fe, Zn, Mn, Cu)	122, 200, 216	119	57, 72, 74, 191	66, 172
Phosphorus	61, 87, 93, 138, 184, 188, 207, 215, 216, 217, 230	8, 40, 148, 190, 192	22, 23, 57, 74, 191	47, 66, 67, 70, 91, 154, 172, 177
Inorganic Salts (K, Ca, Na, Mg)	108, 109, 138, 188, 204, 207, 215, 216, 217, 230	8, 19, 119, 148, 190, 192	22, 23, 57, 72, 74, 191	47, 65, 66, 67, 91, 154, 172, 177
Electrical Conductivity	44, 51, 93, 107, 108, 138, 184, 186, 188, 204, 207, 216, 217	7, 8, 128	22, 23, 44, 51	65, 66, 67, 91, 99, 177
pH	93, 200, 215, 216	40, 148	22, 23	65, 66, 67, 154, 172, 177, 218
Organic Matter	97, 215, 216	40, 119		67, 172

[a]Numbers indicate references in Bibliography.

nitrogen accumulation and the depth of downward leaching, if any, that will occur after applications of animal wastes. Mineralization of organic nitrogen into nitrate nitrogen is most rapid during the first year following application of a waste and steadily declines in subsequent years. A decay series concept of nitrogen mineralization developed by Pratt et al. (159) recognizes this declining rate of nitrate-nitrogen production with time. The rate of mineralization of nitrogen remaining in the soil is determined experimentally each year for the first four or five years after the waste is applied. These data then can be used to estimate the amount of nitrate nitrogen that will come into solution and be available for plant uptake and/or leaching downward through the profile.

Even though nitrogen may be added in excess of that removed by the growing crop, conditions may not be present in the soil which allow mineralization of the organic nitrogen (which is relatively water insoluble and does not leach) into nitrate nitrogen. Nitrate nitrogen can also be removed from the soil solution by denitrification reactions. Both nitrification, an aerobic process of nitrate-nitrogen production from organic and other inorganic nitrogen forms, and denitrification, an anaerobic process by which nitrate nitrogen is converted to various nitrogen gases, are strongly influenced by the oxygen status of the soil. Factors that influence the oxygen content of soils, such as the amount of rainfall, soil texture, drainage, and the rate of oxygen usage by soil organisms, will in turn affect those two processes.

The references listed in Table 10 contain data which verify that nitrate nitrogen will sometimes be leached to lower depths in soil profiles when excess amounts of nitrogen from animal wastes are applied. In some cases, however, there was little if any movement of nitrate nitrogen even when large quantities of wastes were applied. Much of this variability in research results can be explained through differences in soil-water relations. Soils that are well drained usually have a greater potential for nitrate movement after applications of animal waste. Soils that have restricted drainage will usually have a lower potential for nitrate leaching because of insufficient leaching volume or anaerobic conditions which can lower nitrification and increase denitrification. Unfortunately,

there are many soil types which cannot be classified in either of these two general categories. Changing weather conditions add another dimension of variability; extremes of natural rainfall can drastically alter the potential for nitrate movement of a given soil. To summarize, movement of nitrate nitrogen in soil is governed by several factors that together make its prediction difficult.

The potential for nitrate movement on a given soil will be greater with higher rates of waste application. Numerous researchers have compared different magnitudes of waste application on soils receiving the same management in the field and have found that nitrate-nitrogen movement is greater with increasing rates of applied beef waste (107, 108, 122, 216, 217, 230), dairy waste (19), and poultry waste (70). Those data show that more nitrate will be leached if the rates applied at a given site are increased. Care must be taken, however, when extrapolating from one site to another, the effects of a given application rate on depth of nitrate leaching because of the natural variability that exists between soils and local conditions.

Several researchers have measured nitrogen losses in soil after animal waste has been applied. In the greenhouse, Olsen (148) found that 20 to 76% of the nitrogen in dairy manure added to soil was lost through volatilization. Koelliker and Miner (87) reported an unaccountable nitrogen loss of 2,307 kg/ha in a field treated with anaerobic-livestock-lagoon effluent by a sprinkler system. From 31 to 58% of the nitrogen in beef-feedlot manure added to a field in Southern California was unaccounted for in a study by Meek et al. (122). Wallingford et al. in Kansas (216), also applied beef-feedlot manure to a field and measured unaccountable nitrogen losses ranging from 6.7 to 100%. The above losses were attributed to denitrification and illustrate that it can lower significantly the potential for leaching nitrate nitrogen after land application.

Heavy metals and trace elements - Research dealing with the effects of animal waste on the trace element content of soils has been aimed primarily at effects on the availability of these nutrients for plant growth. It

has been shown that animal waste can improve the plant availability of iron, zinc, manganese, or copper in soils (216). With the exception of copper, toxic accumulations of these trace elements does not appear likely. Because copper is added at high concentrations to some swine rations, concern exists that swine waste applications could be toxic to plant growth or cause plant accumulations of copper toxic to animal health. What little research has been done to date on this subject has shown no effect (191) or slightly increased (57, 74) concentrations of copper in soils.

Phosphorus - Concern over the fate of phosphorus applied to the soil in animal waste has led to several researchers measuring the accumulation and movement of phosphorus after land application (Table 10). Unlike nitrogen, phosphorus does not undergo oxidation-reduction reactions in soils. The water solubility of phosphorus is low whether it is bound in organic molecules or in the form of orthophosphates (PO_4). Any ortho-phosphate released from organic matter breakdown quickly enters into reactions which form phosphate precipitates of low solubility.

Increasing rates of waste application on a given site have been shown to increase the accumulation of phosphorus in the zone of waste-soil contact. The magnitude of phosphorus accumulations in soils has increased with increasing application rates of beef waste (61, 70, 138, 188, 207, 215, 216, 217), dairy waste (40, 148, 192), swine waste (23, 72, 74, 191), and poultry waste (66, 67, 154, 177). No significant downward movement of phosphorus has yet been measured in soils after application of beef waste (87, 138, 184, 216, 217, 230), swine waste (72, 74), or poultry waste (47).

Inorganic salts - Applications of animal waste can improve soil fertility through the additions of the inorganic salts potassium, calcium and magnesium. Accumulations of those salts, along with the inorganic salt sodium, have also been implicated in reducing the fertility of soil through their effect on soil salinity. The electrical conductivity (EC) of a water extract from a soil sample is a measurement of soil salinity. The EC, along with the effect of specific inorganic salts, has been evaluated by several researchers after waste applications (Table 10).

The main factor that influences accumulation and movement of inorganic salts in soils after land application is the adsorption of these positively charged ions onto the negatively charged exchange sites found in the mineral and organic-matter fraction of all soils. The amount of each cation that is adsorbed onto exchange sites depends upon the complex factors that control colloidal chemistry, which makes prediction of the accumulation and movement of inorganic salts difficult. However, computer models that predict salt accumulation are available. Accumulation of inorganic salts in the soil is expected to be a more serious problem in the drier regions of the United States where less natural precipitation is available for leaching the salts from the root zone. If specific data regarding the accumulation and movement of inorganic salts is needed, reference should be made to the publications listed in Table 10.

The form of the salt in animal waste can affect the accumulation and movement of that salt in the soil. Most of the calcium and magnesium in wastes are bound in organic molecules which makes their solubilities dependent on the rate of organic matter breakdown. On the other hand, sodium and potassium exist primarily in ionic forms which makes them immediately water soluble and susceptible to leaching.

Measurement of soil EC values have been used by many researchers to evaluate the effect of animal waste applications on the total inorganic salt content of a soil and to relate any build up of inorganic salts to reduced crop growth. High correlations have been found to exist between EC measurements and waste treatment and/or crop growth (5, 44, 65, 91, 108, 177, 204, 207, 216, 217). Other work, however, has shown no effect of animal waste on soil EC measurements (93, 99, 184). Those contrasting EC responses could have been the result of variability in the amount of waste applied, the salt content of the waste, or the amount of soil leaching. In attempting to pinpoint the inorganic salt most responsible for increased EC values after poultry waste applications, Liebhardt and Shortall (91) found that potassium was the salt most highly correlated to EC.

Soil pH - The pH of a soil is a measurement of the acidity or basity of the soil solution. Depending on the previous amount of digestion or

decomposition before application, the soil pH can be quickly raised after animal waste applications due to release of ammonium nitrogen from organic matter breakdown (65, 148, 154). Oxidation of the ammonium nitrogen through nitrification reactions is an acid forming process and can lower the pH (6, 65, 154). Most researchers have measured no change in pH after waste applications (22, 23, 65, 154, 215, 216, 218), indicating that generally soil pH will not be greatly affected by waste applications. Exceptions do exist, however, in that beef wastes have increased soil pH (93, 148, 200), and poultry wastes have decreased soil pH (67, 172, 177). The status of the soil pH before treatment has not been shown to determine whether there will be a pH change.

Biological Properties

The effects of animal waste applications on the total numbers and survival of organisms living in the soil have been studied by several researchers. Giddens et al. (47) found that the numbers of fungi and bacteria were increased in a soil after applications of poultry litter, but the increased population decreased rapidly with time. In a soil percolation study conducted by McCoy (117), it was found that the top 35.6 cm removed bacteria added in dairy manure. Dazzo et al. (40) found that higher rates of dairy manure applications prolong the survival of salmonella and fecal coliforms, suggesting that higher rates of applied waste reduce the ability of a soil to remove organisms.

Beneficial effects of waste application on soil organisms have been reported. Chiang (26) found increased mite predation of corn rootworm and Giddens et al. (47) measured increased numbers of earthworms after animal waste applications.

EFFECT OF LAND APPLICATION ON GROUNDWATER

Applications of animal waste can exceed the capacity of the growing crop to remove waste constituents. Movement of these constituents downward can lead to contamination of groundwater. Because of its ease of movement through soil profiles (see section on Effect of Land Application on Soil Properties - Physical) and because of its ability to lower groundwater quality at low concentrations, nitrate nitrogen is

often regarded as the constituent posing the greatest threat of groundwater contamination. In some regions, groundwater contamination by soluble organic salts is considered to be a threat to groundwater quality. Because phosphorus moves through soil slower than salts or nitrate it is generally not considered a threat to groundwater quality.

The factors affecting nitrate-nitrogen movement in soils, discussed previously in this report, also apply to groundwater contamination. After nitrate nitrogen has moved below the root zone, there is little likelihood of its being removed from the soil by means other than leaching. Denitrification is not likely at these lower depths because it requires an ample supply of easily oxidizable carbon sources which are seldom found at lower soil depths in most regions.

Once it has moved beneath zones where it is susceptible to biological removal, the time needed for nitrate nitrogen to reach groundwater is determined by the rate of downward water movement and the depth to the water table. The factors affecting the rate of downward movement have been and are continuing to receive active investigation. A review of research relating to nitrate-nitrogen movement has been published (18).

Many researchers have shown that applications of animal waste to soils can cause accumulation and downward leaching of nitrate nitrogen (Table 10) and soluble salts. An example is some work done in California (7, 9) in which nitrate nitrogen and soluble salts were found in shallow wells below dairy waste application sites. Nitrate-nitrogen contamination of groundwater is one of the most potentially damaging environmental effects resulting from animal waste applications at rates which provide nitrogen and salts in excess of that which can be immobilized or removed biologically from the soil.

EFFECT OF LAND APPLICATION ON RUNOFF

After an animal waste has been applied to a soil the possibility exists that some of this waste may be transported by rainfall, snowmelt, or irrigation runoff into surface waters. Runoff losses should be minimized

because of possible surface water quality deterioration and because it represents a loss from the soil of potential plant nutrients. Runoff loss of animal waste constituents is a function of runoff quantity and quality. The effects of animal waste applications on the quantity and quality of runoff will be considered separately.

Quantity

The quantity of runoff leaving a field is a function of slope, rate of water application, and soil infiltration rate. Animal waste applications can affect runoff quantity by altering the soil infiltration rate. As was discussed in the section on the Effect of Land Application on Soil Physical Properties, it has been shown that infiltration rates will generally be improved after applications of animal waste. Although liquid wastes that are high in the monovalent cations sodium, potassium, and ammonium potentially could lower infiltration rates by causing the soil to disperse, only lowered runoff losses have been measured by researchers who have applied beef waste (186, 231) and dairy waste (60, 116, 229). In drier regions reduction of surface runoff is an important agronomic benefit of land application because of the moisture conservation that results. Cases of increased runoff losses are less common; beef-feedlot runoff water was found to increase irrigation runoff (101).

Quality

The quality of runoff leaving a field that has been treated with animal waste has been found to be dependent upon time of application, presence of vegetative cover, degree of incorporation, and the amount applied. Other controlling factors such as intensity of rainfall and slope of the field are likely to affect the amount of nutrients lost in runoff, but these factors have not been investigated in relation to animal waste applications.

Several researchers have examined the effect of applying dairy waste to frozen soils during the winter. In earlier work on runoff losses of manure spread during the winter, Midgley and Dunklee (125) found that significant quantities of nitrogen, phosphorus, and potassium were lost in the runoff. The loss of potassium was greater than that of nitrogen and phosphorus

because of the greater solubility of potassium in the manure.

In a study conducted by Sutton et al. (192), it was found that liquid dairy waste applied to frozen ground at a rate of 130 cumulative wet t/ha increased ammonium nitrogen and total coliform in the runoff, but did not affect total nitrogen measured in the runoff.

A comparison of runoff quality from plots of frozen soil receiving dairy waste applications in the winter and from plots receiving summer applications was made by Minshall et al. (134). It was found that up to 20% of the nitrogen, 13% of the phosphorus, and 33% of the potassium added in the manure was lost in runoff from winter-applied manure plots, while losses in surface runoff from plots receiving the summer applications were less than from plots receiving no manure.

Hensler et al. (58) compared the effects of winter to spring dairy manure applications. They found that nutrient losses from manure applied in winter were extremely variable; 3.4 to 26.9 kg/ha of nitrogen was lost from the winter-applied manure plots. Applications of manure in the spring did not result in any runoff loss of nitrogen, phosphorus, or potassium.

The effect of vegetative cover on fields receiving waste applications on runoff losses was studied by Young (229). When dairy manure was applied to frozen alfalfa land 30% of the applied nitrogen and 6% of the applied orthophosphate was lost in spring runoff, and total nutrient loss from the alfalfa plots was greater than from the check plots. However, when the same rate was applied to frozen, plowed land, total nutrient losses were only slightly greater than those from the check plots which received no treatment. This was probably due to the rougher surface of the plowed land which reduced total runoff. Hensler et al. (58) also found that applying dairy manure to sod covered fields created a greater likelihood of nutrient loss than from applying the same waste to fallow fields. It was suggested that the vegetation prevented the waste components from coming in contact with the soil, thereby increasing the likelihood of waste

constituents being removed in the runoff.

When animal wastes are incorporated into the soil after application, nutrient losses in the runoff are usually low. Nutrient losses in snowmelt runoff were found by Young (229) to be only slightly higher from ground that had received 44.8 t/ha of dairy waste in the fall and plowed under than from plots that received no treatment. Minshall et al. (134) found that nutrient losses in runoff from check plots were greater than from plots having received manure in the summer and plowed under. In a study where up to 67 t/ha of beef-feedlot manure were applied for two years and plowed under, Mathers and Stewart (186) found fewer nutrients in irrigation tailwater than was applied by the irrigation water itself.

Increasing the rates of manure applied at a given site can increase the amounts of nutrients lost in surface runoff. McCaskey et al. (116) found that plots receiving low rates of applied dairy waste did not contaminate surface water as much as plots receiving higher rates of application.

Research has shown that applications of animal waste to frozen ground or to ground with vegetative cover will increase the likelihood of lowering the quality of surface runoff. Incorporating the waste after application is a management practice that reduces surface runoff contamination.

EFFECT OF LAND APPLICATION ON PLANTS

Crop Yield

Positive results - Improved soil productivity is the most beneficial result of applying animal waste to soils. Enhanced soil availability of plant macro- and micronutrients has been shown to be the major factor improving plant growth after waste applications. Positive effects on soil physical properties, such as those discussed in the section on the Effect of Land Application on Soil Properties, have also been shown to improve soil productivity.

Some of the first soil productivity experiments involved the use of

animal manures, and more recent research has further shown that crop yields can be increased after applications of beef, dairy, swine, and poultry waste (Table 11).

When optimal rates of chemical fertilizer and animal waste are applied on separate plots, in most years the effects on yields will be equal. It has been shown, however, that comparative yields can be affected by extremes of soil moisture. In dry years plots receiving manure have out-yielded those receiving chemical fertilizer, while on the same plots in wet years chemical fertilizer has been superior (118, 218). An explanation offered was that manure improved soil moisture availability which increases yield in dry years, while in wet years manure promotes denitrification which lowers nitrogen availability and lowers yields.

Negative results - Several researchers who applied large amounts of animal wastes have measured yields that were depressed relative to control plot yields or relative to plots obtaining maximum yields (Table 11). Increased soil salinity was thought responsible in many studies in which yields were found to decrease (107, 108, 109, 138, 177, 216, 217), and in only one case (23) was there found no accumulation of soluble salts in soils that had showed depressed plant growth. Several experiments have shown no negative effect on yields due to heavy rates of animal waste applications (23, 51, 59, 93, 167, 172, 196), but when soil salinity was measured no build-up of soluble salts was found (51, 93, 196).

Seed germination and seedling growth can be lowered by saline soil conditions and by toxicity from high ammonium concentrations in the soil. Reduced germination or slow seedling growth has contributed to reduced yields of crops grown on soils that had received large applications of animal wastes (5, 107, 177, 216). Seigel et al. (179) attributed plant toxicities specifically to the ammonium released by decomposition of the uric acid in poultry manure. Because the rate of ammonium production is greatest soon after application or during the spring after winter applications, plant toxicities are most likely to occur during those periods.

Because no other negative plant growth factor has been reported at this

Table 11. REFERENCES ON CROP YIELDS AFFECTED BY ANIMAL WASTE APPLICATION.[a]

	Reference numbers			
	Beef	Dairy	Swine	Poultry
Yields increased	1, 35, 44, 51, 60, 61, 108, 138, 167, 175, 188, 196, 207, 216, 217	1, 59, 60, 118, 150, 206	44, 51, 54	25, 67, 121, 127, 154, 218
Yields decreased	35, 107, 108, 109, 138, 167, 216, 217		23	177

[a] Numbers indicate references in Bibliography.

time, the main agronomic concerns about applying large amounts of animal wastes should be decreased plant growth due to soil salinity and ammonium toxicity. Management of soil receiving high application rates of manure should be similar to management of irrigated soils where the salt concentration of irrigation water is high.

Nutrient Recovery

Removal of plant nutrients applied in animal waste is an important consideration in maintaining soil viability. Maximum removal is desirable so that a build-up of excess plant nutrients is minimized. Maximum recovery of plant nutrients occurs usually at application rates which give maximum crop yields (61, 216, 217). Nutrient recovery can be depressed by application rates which cause yield decline (59, 150, 216, 217).

Animal Toxicities

Nitrate nitrogen - Forages high in nitrate nitrogen can be hazardous to animal health if ingested. Major factors influencing the accumulation of nitrate nitrogen in plants are moisture stress on the plant and nitrate-nitrogen availability in the soil (228). Release of nitrate nitrogen from decomposition of animal manures will increase the concentration of this ion in the soil solution and increase the likelihood of uptake by plant roots. Applications of beef waste (108, 160, 167, 216) and dairy waste (160, 206) have increased the nitrate-nitrogen content of plants to levels potentially toxic to animal health. In other studies, nitrate-nitrogen content has not been increased by applications of beef waste (109, 138, 167). It has been recommended that forages grown on soils receiving greater than 30 t/ha/yr of dry beef-feedlot manure or on soils that have received large single applications of manure be analyzed for nitrate nitrogen before being fed to livestock (216).

Copper and arsenic - Copper is sometimes added to swine rations as a growth stimulant. Plants high in copper concentrations can be toxic to animal health if ingested (202). Consequently, there has been concern over the possibility of copper accumulations in plants grown on soils

receiving swine wastes. Humenik et al. (74) reported copper concentrations in grasses grown on lysimeters receiving waste from swine grown on high copper rations were above 30 ppm, the toxic threshold reported for sheep. Hedges et al. (57) found a trend toward higher copper in corn grown on a plot that had received high copper feces. Applications of poultry manure increased the copper content of coastal bermuda grass in a study by Wilkinson et al. (222), but not to toxic levels for sheep.

The fate of arsenic added to poultry rations as a feed additive has been studied by Morrison (135). It was found that the arsenic content of legumes was unaffected by applications of poultry litter that contained measureable amounts of arsenic.

Grass tetany - Grass tetany has been reported in animals grazing on pastures that had previously received poultry litter. Grass tetany is a nutritional disease occuring when there are low blood levels of magnesium. Several factors are thought to cause this disease, one of them being a low magnesium to potassium ratio in forages consumed by the affected livestock. Applications of poultry litter can aggravate the disease by raising soil potassium more than soil magnesium, resulting in an antagonistic effect on magnesium uptake (80, 224). As one preventive measure, it has been recommended that poultry litter not be applied to pasture at rates greater than 9 t/ha (80).

SECTION VII

APPLICATION RATES BASED ON WASTE CONSTITUENTS

INTRODUCTION

One objective of this project was to gather existing experimental data that could be used to formulate application guidelines for the 12 climatic regions. It was thought that by eliminating the variation due to climate and waste type, specific application rates could be formulated for each region based on that region's experiment results. Examination of the published research has shown, however, that variability existing between the characteristics, management, and application of the wastes produced at different livestock production sites does not allow application rate recommendations based only on climate and waste type.

Most research on land application of animal waste has been aimed at finding application rates which provide ample nutrition for a growing crop without creating soil conditions that are toxic to plant growth. Many researchers have compared different rates of waste application at a given location where the soil, crop, and management practices were held constant. Certain application rates in a given study have usually produced maximum crop yields or have reduced crop growth. Most researchers, however, have been reluctant to base application rate recommendations on research findings because of the tremendous variability that exists between local waste composition, management practices, soil types, and weather. When recommendations are published, they are usually based on factors which the researcher has found experimentally to be of primary concern or that he felt would be important in the future.

There have been several criteria used to formulate application rates. A discussion of criteria that have been published will be followed by a discussion of criteria judged to be the most acceptable on a nationwide basis.

EXISTING APPLICATION RATE CRITERIA

Nitrogen

Most application rate recommendations are based on achieving maximum yields due to improved availability of plant nutrients in the soil. Because nitrogen is frequently the nutrient that limits plant growth and because nitrogen poses a great threat to groundwater contamination, this element is most often used as the basis for determining application rates.

Plant availability of nitrogen is controlled by the inorganic nitrogen content of the waste before application and by the rate of mineralization of organic nitrogen into inorganic nitrogen forms in the soil after application. The factors that influence nitrogen mineralization have been discussed in the section on the Effect of Land Application on Soil Chemical Properties in relation to movement and accumulation of nitrate nitrogen in the soil. Because nitrate nitrogen is the predominant form of nitrogen taken up by plants, factors that control accumulation and movement of nitrate nitrogen will also control plant availability of nitrogen.

Several researchers have published ways to calculate application rates for specific waste types based on the plant availability of the waste nitrogen. In Kansas Herron and Erhart (61) found that from two-thirds to three-quarters of the nitrogen in beef-feedlot manure was available to grain sorghum over a four-year period. Koelliker et al. in Iowa (88) measured the nitrogen balance of a soil receiving swine-lagoon effluent and concluded that yearly applications should be limited to 30.5 cm or less based on a nitrogen application rate of 672 kg/ha/yr. Marriott and Bartlett in Pennsylvania (105) estimated that in order to prevent movement of nitrogen below the root zone, application rates of dairy-manure slurry should not supply more than 560 to 672 kg/ha/yr of nitrogen.

The extension services of several states have developed animal waste application guidelines based partly on the nitrogen content of the waste. Indiana (30) has published application rate guidelines for beef, dairy, swine, and poultry wastes. Recommended application rates are expressed in animals per hectare and are based on the waste adding 252 kg/ha of nitrogen. It is assumed that 50% of the nitrogen is lost between excretion and application.

North Carolina (140, 141, 142, 143) determines application rates by calculating the quantity of waste needed to satisfy a nitrogen soil test. The swine, dairy, or poultry waste must be analyzed for nitrogen before application.

Iowa (211) has developed tables that can be used to determine the acres of land needed for application of swine and beef waste. These tables are based on the waste handling system and the pounds of nitrogen to be added to the soil.

Ohio (139) uses a decay series concept of nitrogen mineralization to calculate the application rates for animal manures. This concept is further explained in a following section entitled "Proposed Criteria: Nitrogen Availability". Ohio assumed that 30% of the nitrogen is mineralized the first year and that 5% of the remaining residual nitrogen will be mineralized each subsequent year. Application rates can thus be reduced each year while maintaining a constant availability of nitrogen in the soil.

Kansas (157) also used a nitrogen decay series concept to develop application guidelines for beef-feedlot manure. Decay series constants which vary according to the nitrogen content of the waste were borrowed from Pratt (159). Wastes with higher nitrogen contents will have a higher percentage of nitrogen becoming available each year.

Maine (92) guidelines for application of animal wastes are based partly on the nitrogen content of the waste. Recommended application rates range from 0 to 560 kg/ha of nitrogen depending on the soil type and whether the management objective is complete recycling of the nitrogen through the crop or simply disposal of the waste.

Soluble Salts

It has been shown that large applications of animal waste can be toxic to plant growth by creating saline soil conditions (see the section on the Effect of Land Application on Plants). Application rates based on the salt content of the waste have been developed so that decreased crop

growth after land application can be avoided. Except for wastes low in nitrogen, application rates based on salt content generally provide nitrogen in excess of crop usage. Application guidelines based on a salt content of the waste will, therefore, not be used as a means to determine the most efficient use of the nitrogen, but as a method to determine maximum amounts that can be applied without decreasing crop growth.

Powers et al. developed guidelines for application of beef-feedlot manure (157) and lagoon water (156) based partly on the total salt content of the waste. Maximum application rates permissible without causing excessive salt build up in the soil are calculated by determining the salt (Na, Ca, K, and Mg) content of the waste, the salt content of the irrigation water, soil type, and the amount of irrigation water that is applied. It is recognized that crops vary in their ability to withstand salt accumulations in the soil (see 156 and 157), and that maximum tolerable salt levels in the soil will be determined by the type of crop grown. An example calculation will be discussed in the section on Application Techniques.

Soil Type

Soil type influences the application rate because it controls the amount of salt leaching out of the root zone, nitrate-nitrogen movement to groundwater, and nitrogen that is lost to the air through processes of volatilization and denitrification. The soil property most important here is drainage or lack of drainage because of its influence on aeration and water movement.

The variability existing between soils makes the task of basing application rates on soil type difficult. The extension service of North Carolina (140, 141, 142, 143) has listed in their animal waste application guidelines the relative nitrate leaching potential of typical soil series found in that state. It was noted that soils of high nitrate leaching potential should receive smaller applications of animal waste, but no attempt was made to quantitate application rates based on soil type.

Maine's (92) guidelines for animal waste application have an extensive listing of the maximum nitrogen application rate for each soil series found within that state. The maximum rates are based on decriptions by Soil Survey of the physical and chemical characteristics of each soil type and on research results.

If the entire nitrogen requirement of a crop is to be satisfied by animal waste applications, very high rates of applications may be needed for the first several years before sufficient residual nitrogen is built up in the soil. In such cases it is possible that toxic levels of salt may accumulate in the soil and reduce crop growth during the first couple of years. For that reason, it is necessary that guidelines have the ability to detect application rates that might cause toxic salt accumulations in the soil. Such guidelines should include salt balances based on the soluble salt content of the waste, salt concentration of any added irrigation water, the amount of salt leaching out of the profile, and the salt tolerance of the crop. This type of guidelines has been described by Powers et al. (156).

Crop Quality

Applications of animal waste can lower crop quality by causing toxic accumulations of nitrate nitrogen and by creating nutrient imbalances that can cause grass tetany. Pratt et al. (160) in Southern California found that in order to avoid accumulation of nitrate nitrogen in sudangrass in a particular management system studied, 8.6 and 29 dry t/ha were safe limits for applying undigested dairy cattle slurry and solid dairy manure, respectively.

Potentially toxic levels of nitrate nitrogen were found by Wallingford et al. (216) in corn forage grown on soil that had received applications of solid beef-feedlot manure. It was recommended that irrigated forage grown on soils receiving greater than 30 t/ha/yr of dry manure, on soils that had received large single applications of manure, or those grown under moisture stress be analyzed for nitrate nitrogen before being fed to livestock.

Wilkinson et al. in Georgia (224) has recommended that no greater than 9 t/ha/yr of poultry manure be applied to tall fescue pasture systems in order to avoid animal toxicities from nitrate-nitrogen accumulations and from potassium-magnesium imbalances that could cause grass tetany.

PROPOSED CRITERIA: NITROGEN AVAILABILITY

An estimation of nitrogen mineralization coupled with the nitrogen usage of the crop, with an awareness of potential salt toxicities, appears at this time to be the best criteria on which to base application rate calculations. From the standpoint of obtaining optimal crop nutrition and minimizing the potential for groundwater contamination, nitrogen is the most logical constituent on which to base application rates.

The amount of available nitrogen present in the soil before application must be known so that application rates can be adjusted according to the amount of additional nitrogen needed to obtain optimum yields. Kriz et al. (140, 141, 142, 143) proposed using soil test values as part of the criteria for establishing application rate guidelines in North Carolina. This data can be obtained from soil testing laboratories which can analyze soil samples to determine the kg/ha of available nitrogen. These tests are relatively simple and rapid.

Once the available nitrogen content of the soil has been determined, it is necessary to find the recommended rate of inorganic nitrogen fertilizer needed to satisfy demands of the particular crop. These data are available through state extension agencies. Animal waste application rates can then be calculated based on the nitrogen requirement of the crop, the soil test value, and estimation of the mineralization rate for that particular waste, and estimated losses of nitrogen from the soil due to volatilization and denitrification. The individual operator can determine for himself whether to supply all of the needed nitrogen by applying animal waste or by supplementing the waste nitrogen with inorganic nitrogen fertilizers.

At the present time, the best method to express the estimation of nitrogen mineralization is one which uses a decay series. As described by Pratt et al, (159), the decay series concept is based on mineralization of organic

nitrogen into inorganic or available nitrogen. The rate of mineralization will be most rapid in the first year after application, and will decrease in subsequent years. For example, 40% of the applied nitrogen might become available in the first year, 25% of the residual nitrogen in the second year, 6% of the residual nitrogen in the third year, and 3% of the residual nitrogen in the fourth and all subsequent years. That decay series would be expressed as 0.40, 0.25, 0.06, 0.03. The percentages after the first year refer to the organic nitrogen remaining in the soil and not to the original amounts of nitrogen applied.

Wastes that are higher in nitrogen content will have a faster rate of decay; a dry-beef manure with a 1.5% nitrogen may have a decay series of 0.35, 0.15, 0.10, 0.05, while a similar manure with 1.0% nitrogen may have a decay series of 0.20, 0.10, 0.05.

Climate affects decay series by increasing the decay constants for the later years in the series, but does not affect the decay constants for the first several years. For example, a decay series from a warm climate where nitrogen mineralization would proceed for a larger portion of the year might be 0.35, 0.15, 0.10, 0.075, 0.05, 0.04. In contrast, the decay series of the same waste applied in a colder climate might be 0.35, 0.15, 0.10, 0.05, indicating a slower rate of decay in the later years.

Animal wastes with a large percentage of the nitrogen in the form of inorganic nitrogen or in the form of chemicals such as uric acid or urea which are quickly broken down into inorganic nitrogen, will have high decay constants for the first several years of the series. In contrast, wastes that have lost significant quantities of nitrogen through ammonia volatilization, or wastes that have lost nitrogen through leaching after decomposition during storage, will have decay constants that are low for the first years of a series.

A nitrogen decay series concept of determining application rates could have widespread adaptability because the decay constants can be determined by experimental data. Some existing data on nitrogen availability might be

used to calculate decay series constants, but most of these constants must come from experimental data yet to be gathered. Variables such as soil type, waste nitrogen content, and climate, must be accounted for when determining decay series constants.

The expected nitrogen loss from volatilization and denitrification must also be considered when applying animal waste. If significant quantities of nitrogen are lost in this manner, larger quantities of nitrogen can be applied to the soil. If the soil is to be used as a disposal medium, losses of nitrogen from volatilization and denitrification may significantly increase allowable application rates. When animal waste is to be used as a nitrogen source, additional quantities may be needed to compensate for the nitrogen lost through volatilization and denitrification.

If the entire nitrogen requirement of a crop is to be satisfied by animal waste applications, very high rates of applications may be needed for the first several years before sufficient residual nitrogen is built up in the soil. In such cases it is possible that toxic levels of salt may accumulate in the soil and reduce crop growth during the first couple of years. For that reason, it is necessary that guidelines have the ability to detect application rates that might cause toxic salt accumulations in the soil. Such guidelines should include salt balances based on the soluble salt content of the waste, salt concentration of any added irrigation water, the amount of salt leaching out of the profile, and the salt tolerance of the crop. This type of guideline has been described by Powers et al. (156, 157).

Example Formulation

Several formulas can be used to determine application rates based on waste constituents. These should incorporate the nitrogen requirement of the crop, the available nitrogen in the soil, expected nitrogen loss from denitrification and volatilization and the mineralization rate of nitrogen (decay series). If the nitrogen content of the waste is constant from year to year, a possible formula expressed in English units might be

$$R_J = \frac{N_c - N_s + N_L}{20C\left[D_1 + \sum_{j=1}^{J-1} D_{j+1}\left(1 - \sum_{i=1}^{j} D_i\right)\right]} \qquad (1)$$

where R_J = application rate for the Jth year of application (T/A)

N_c = nitrogen used by the crop (lb/A)

N_s = nitrogen available in the soil (lb/A)

N_L = nitrogen loss expected from denitrification and volatilization (lb/A)

C = concentration of nitrogen in waste (percent)

D_1 = first term in decay series (dimensionless)

D_{j+1} = (j+1)th term in decay series (dimensionless)

D_i = ith term in decay series (dimensionless)

The application rate R_J of the Jth year may be limited to a maximum value R_m because of plant-toxic substances in the waste. The value of R_m might also be determined by a potential for water pollution from substances in the manure other than nitrogen. Limits on R_J are expressed by

$$R_J \leq R_m \qquad (2)$$

If there is potential for plant toxicity from the build-up of inorganic salts, R_m is a function of the soil texture T, the quality of the irrigation water I, the annual precipitation P, and the salt concentration S in the waste. The value of R_m is a function of S, I, P, and S expressed as

$$R_m = f(T, I, P, S) \qquad (3)$$

The function f(T, I, P, and S) is usually obtained from graphs based on local data as seen in a later example.

To use this proposed system, it is seen from equations (1) and (2) that values of N_c, N_s, N_L, C, $D_{1,2...}$ and R_m must be known. The nitrogen used by the crop N_c is known for most climatic regions, soils, and crops. The nitrogen available in the soil N_s and the concentration of the nitrogen in the waste C can be obtained by analysis. However, the

expected nitrogen loss N_L; the decay constant $D_{1,2...}$; and the limiting rate R_m are not well-known for each region and may need to be obtained through additional research (See the section entitled "Research Needs"). If a value for N_L is not known, it is safest to assume it to be zero.

Agricultural extension agents are usually the best sources of information on how to obtain values of N_c, N_s, N_L, C, $D_{1,2...}$ and R_m for local soil and climatic conditions.

Solutions for equations (1) and (3) have been determined for Kansas conditions and are presented in Tables and Graphs by Powers et al. (156, 157). An example calculation for beef-feedlot manure application in Kansas is given below.

Example Calculation

Introduction - This example calculation of R_J is based on the amount of nitrogen in the manure. The calculation of R_m is based on the need to avoid adding more salts than can be leached from the profile by natural precipitation. Generally salt build-up may be a problem west of about the 98th meridian. The term salt refers to the inorganic salts of sodium, potassium, calcium, and magensium. A salt build-up in the soil will limit the uptake of water by plants. A measure of the salt build-up (salinity) is the electrical conductivity of the soil water measured on a saturation extract from the soil. The soil having a saturation extract with an electrical conductivity of 4 or more millimhos per centimeter (mmhos/cm) is classified as saline. Because irrigation water also contains soluble salts, its salt concentration must also be considered when manure is applied to irrigated land. The operator wants to manage his manure and water applications to prevent these salt accumulations. The following example shows how to apply manure to the soil to supply proper amounts of nitrogen while avoiding salt build-up.

Necessary Information - In order to determine the application rate from equations (1), (2), and (3) several factors must be known. These factors are (1), the nitrogen use of the crop to be grown on the area of application; (2), the soil test giving the available nitrogen in the soil; (3), the quality of the irrigation water, i.e. the electrical conductivity

or soluble salt concentration; (4), the manure analyses (This analyses should include the percent nitrogen, the percent water, and the percent salts of calcium, magnesium, potassium, and sodium); (5), the texture of the soil upon which the manure will be applied; and (6) the expected nitrogen loss from volatilization and denitrification.

For this example assume that the crop to be grown is sorghum, 120 lbs. of nitrogen are needed for the growth of the sorghum, and the electrical conductivity of the irrigation water is 0.65 mmhos/cm. The manure is typical of Western Great Plains beef-feedlots and contains 50% water, 1.3% nitrogen, 0.5% phosphorus, 1.09% potassium, 0.23% sodium, 0.78% calcium, and 0.4% magensium. This manure is to be applied upon a soil of medium texture having 20 pounds of available nitrogen. It is assumed that there will be no loss of nitrogen from volatilization or denitrification.

In this example, first calculate the amount of manure that will supply the desired amount of nitrogen, and then see if that amount of manure will supply excessive amounts of toxic substances such as soluble salts.

Rate Based on Nitrogen Content - Equation (1) can now be used to calculate the application rate R_J provided values of D are known for C equal to 1.3. Only values of D for C equal to 3.5, 2.5, 1.5, and 1.0 are known for our example. Therefore, R_J for C equal to 1.3 will be estimated by linear interpolation between values for C equal to 1.5 and 1.0. The values of D for C equal to 1.5 and 1.0 are 0.35, 0.15, 0.10, 0.05, and 0.20, 0.10, 0.05.

Using values of $N_c - N_s + N_L = 120 - 20 + 0 = 100$, $C = 1.0$, $D_1 = 0.20$, $D_2 = 0.10$, and $D_3 = 0.05$ it is seen from equation (1) that the application rate R_J for the first, second and third years is given by:

$$R_1 = \frac{100}{(20)(1.0)[0.20]} = 25 \text{ Tons/Acre}$$

$$R_2 = \frac{100}{(20)(1.0)[0.20+0.10(1-0.20)]} = 17.8 \text{ Tons/Acre}$$

$$R_3 = \frac{100}{(20)(1.0)[0.20+0.10(1-0.20)+0.05(1-0.20-0.10)]} =$$

$$\frac{100}{(20)(1.0)[0.32]} = 15.6 \text{ Tons/Acre}$$

Simarly for $N_c - N_s + N_L = 120 - 20 + 0$, $C = 1.5$, $D_1 = 0.35$, $D_2 = 0.15$, $D_3 = 0.10$ and $D_4 = 0.05$ it is seen that the application rate R_J for the first, second and third years is 9.6, 7.4, and 6.7 tons/acre.

Linear interpolation between 25 tons/acre when C is 1.0 and 9.6 tons/acre when C is 1.5 yields 16 tons/acre as the application rate R_J for the first year of application of our manure with 1.3 percent nitrogen.

For convenience, solutions to equation (1) have been tabulated for $N_c - N_s + N_L = 50$, 100, and 200 lbs. of nitrogen and for C = 3.5, 2.5, 1.5, and 1.0. These solutions are presented in table 12 for up to the 20th year of application.

Maximum Rate for Irrigated Land - To calculate the maximum rate (R_m of equation 2 and 3) to avoid a salt build-up, the salt concentration of the irrigation water and the salt concentration of the manure must be known. Salt concentration in the manure is estimated by the sum of the percentages of the sodium, potassium, calcium, and magnesium. In this particular case, add the sums of 1.09% for potassium, 0.23% for sodium, .78% for calcium and 0.40% for magnesium to obtain a total of 2.5% salt on a dry weight basis.

This data along with the texture of the soil can now be used to determine the maximum amount of salt which can be applied to a soil for a given year. Several figures have been prepared (157) which can be used to determine the maximum amount of manure to be applied to the soil. Figure 4 is for a low salinity and on a medium textured soil. Although sorghum can be grown on a soil of medium salinity, (that with a saturation extract of 6 mmhos/cm) the low salinity level, (that with a saturation extract of less than 4 mmhos/cm) was chosen here. From Figure 4 it is seen that for an electrical conductivity of .65 for the irrigation water and 2.5% salt in manure that the maximum annual application rate of dry manure should not exceed 19 tons per acre. The dashed line in the figure illustrates how this value was determined.

Table 12. MANURE APPLICATION RATES NEEDED TO INSURE 50, 100, OR 200 POUNDS OF AVAILABLE NITROGEN PER ACRE.[a]

Nitrogen Desired (lbs/A)	Nitrogen In Manure[b] (percent)	Year of Application							
		1st (T/A)	2nd (T/A)	3rd (T/A)	4th (T/A)	5th (T/A)	10th (T/A)	15th (T/A)	20th (T/A)
50	3.5	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8
	2.5	2.5	1.8	1.7	1.6	1.5	1.4	1.3	1.2
	1.5	4.8	3.7	3.4	3.1	3.0	2.6	2.3	2.1
	1.0	12.5	8.9	7.8	7.2	6.6	4.8	4.0	3.5
100	3.5	1.9	1.8	1.8	1.8	1.7	1.6	1.6	1.5
	2.5	5.0	3.6	3.4	3.3	3.1	2.7	2.5	2.4
	1.5	9.6	7.4	6.7	6.3	6.1	5.1	4.6	4.2
	1.0	25.0	17.8	15.6	14.3	13.1	9.6	7.9	6.9
200	3.5	3.8	3.6	3.5	3.5	3.4	3.3	3.2	3.1
	2.5	10.0	7.3	6.9	6.6	6.3	5.5	5.0	4.7
	1.5	19.1	14.8	13.1	12.6	12.1	10.3	9.1	8.4
	1.0	50.0	35.7	31.3	28.6	26.3	19.3	15.9	13.9

[a] Application rates are on the dry weight basis.

[b] Nitrogen contents are on the dry weight basis. Adapted from Pratt (159).

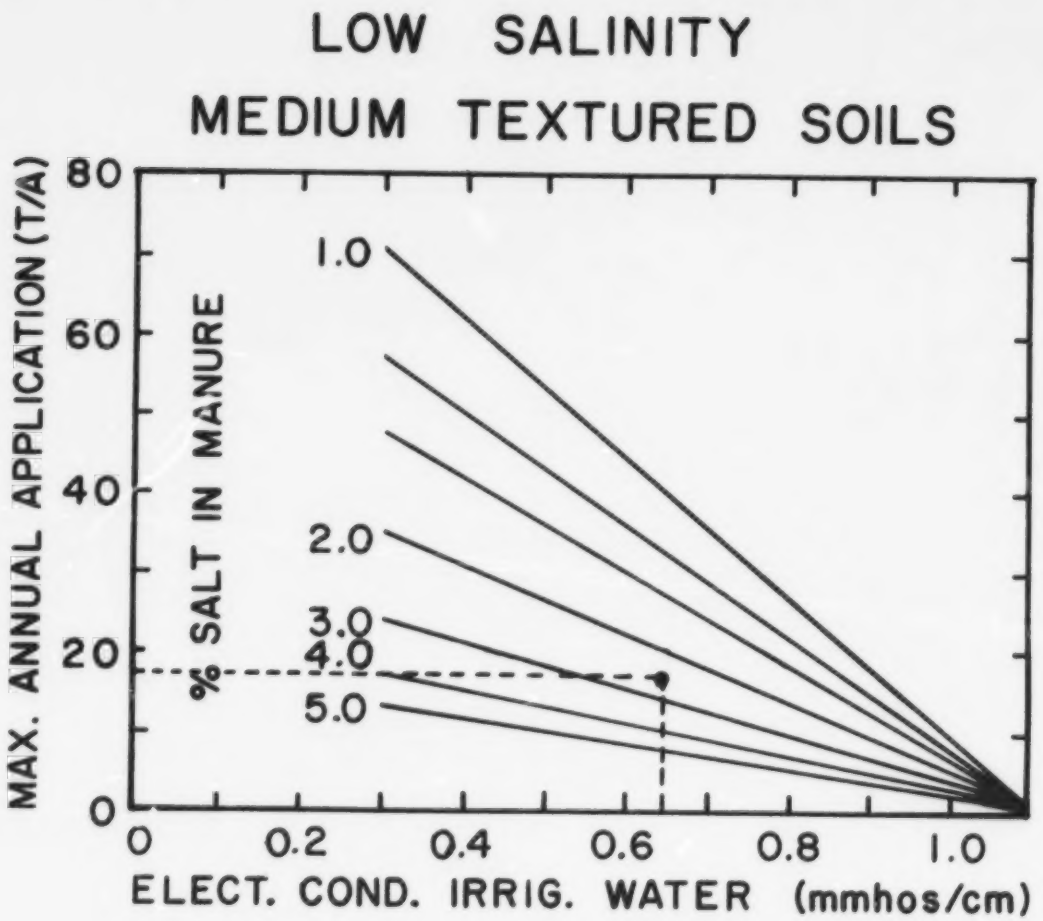

Figure 4. Annual manure application rates for a resulting LOW SALINITY (electrical conductivity of the soil water, saturation extract, of 4 or less) on a MEDIUM TEXTURED SOIL. The rates are on the dry weight basis.

Because this value is more than the 16 tons per acre needed to supply 100 lbs. of nitrogen, a saline soil is not expected to develop in this case. The calculations are on the dry weight basis and so we need to calculate the tons of manure to be added on the wet weight basis. The data show that the manure is 50% moisture using Table 13 we see that 32 tons of material with 50% moisture should be added.

The Dispersion Hazard For Irrigated Land - Salt build-up is not the only hazard when applying manure to the soil. An improper balance of sodium and potassium in relation to calcium and magnesium salts can cause soil aggregates to break down into the individual clay particles, i.e. cause soil aggregates to disperse. The dispersed clay then moves down into the profile, blocks soil pores, and reduces infiltration of water into the soil. Some irrigation water is high enough in sulfates to cause soluble calcium to precipitate. That may reduce the amount of soluble calcium and cause an imbalance between soluble sodium plus potassium and soluble calcium plus magnesium. Such an imbalance would again cause the soil to disperse.

If the ratios of the weight of sodium and potassium to the total weight of the salt (in the manure plus irrigation water), are more than 0.65, dispersion might occur on a medium textured soil maintained at low salinity. When the ratio of sodium plus potassium to total inorganic salts exceeds the above value, or the irrigation water is high in soluble sulfates, seek professional advice from a county agent or from state soil testing laboratories.

To calculate the ratio of the weights of potassium plus sodium to total salts, determine the weight of the sodium plus potassium and the weight of all salts added to the soil. In our manure we would have .0109 tons of potassium, 0.0023 tons of sodium, and 0.025 total tons of salt in each ton of dry manure solids. Sixteen tons of dry manure solids would supply 0.1744 tons of potassium, 0.0368 tons of sodium, and 0.4 total tons of salt. Total tons of salt added from the irrigation water is estimated by: 0.95 x electrical conductivity x the acre feet of water added, or for 2 acre feet (0.95 x 0.65 x 2 = 1.24) tons of salt from the irrigation water.

Table 13. CONVERSION FACTORS FROM DRY WEIGHT TO WET WEIGHT.

% Water	Factor	% Water	Factor	% Water	Factor
10	1.11	35	1.54	60	2.50
15	1.18	40	1.67	65	2.86
20	1.25	45	1.82	70	3.33
25	1.33	50	2.00	75	4.00
30	1.43	55	2.22	80	5.00

EXAMPLE: If the application rate for dry manure is 20 tons per acre, the application rate for manure containing 30% moisture is 1.43 X 20 = 28.6 tons per acre.

If the water analyses shows that 25% of the salt is soluble sodium, there is (0.25 x 1.24 = 0.31) tons of sodium added from the irrigation water.

Using these data one can find the ratio of the sodium plus potassium to the total salts added. This would be (0.1744 + 0.0368 + 0.31)/(0.4 + 1.2) = 0.32 which is below the critical ratio of 0.65.

Maximum Rate R_m for Nonirrigated Land - Because irrigation water helps to leach soluble salts from the soil profile, manure application rates must be reduced if irrigation water is not added. However, natural precipitation helps to leach soluble salts. In areas of higher rainfall, more manure can be added than in low rainfall areas without creating saline soils. We use the ratio of the average annual precipitation to percentage of salt in the manure and the soil texture in Figure 5 to find maximum application rates on nonirrigated land. The salt concentrations in the manure and the texture of the soil are determined as previously described. Assume that you want to apply the manure above to a medium textured soil in an area where the annual precipitation is 28 inches. Again using the concentration estimate of 2.5% for total salts find the value to use on the horizontal axis of Figure 5 by dividing the annual precipitation by the manure salt percentage (28/2.5 = 11.2). Using 11.2 in Figure 5 it is seen that the annual application should be less than 14 tons per acre of dry manure solids. This is equivalent to 28 tons of manure having 50% moisture. At first it appears as though 100 lbs of nitrogen cannot be supplied to the nonirrigated land because it was earlier established that 16 tons per acre of dry manure is needed and if this amount is used a salt build-up will result. However, on further examination of Table 12 we see that to supply 100 lbs. of nitrogen per acre continuously over a 20-year period that the second year application will be considerably less than the first. Also this maximum level is the maximum annual application rate. Therefore in this particular case, the value of 14 tons could be exceeded by 2 tons for nonirrigated soils the first year without causing serious salt build-up.

The Dispersion Hazard for Nonirrigated Land - To calculate the dispersion hazard add the total concentrations of the calcium and the sodium divided by the total salts which would be (0.174 + 0.037)/(0.40) = 0.527. Again

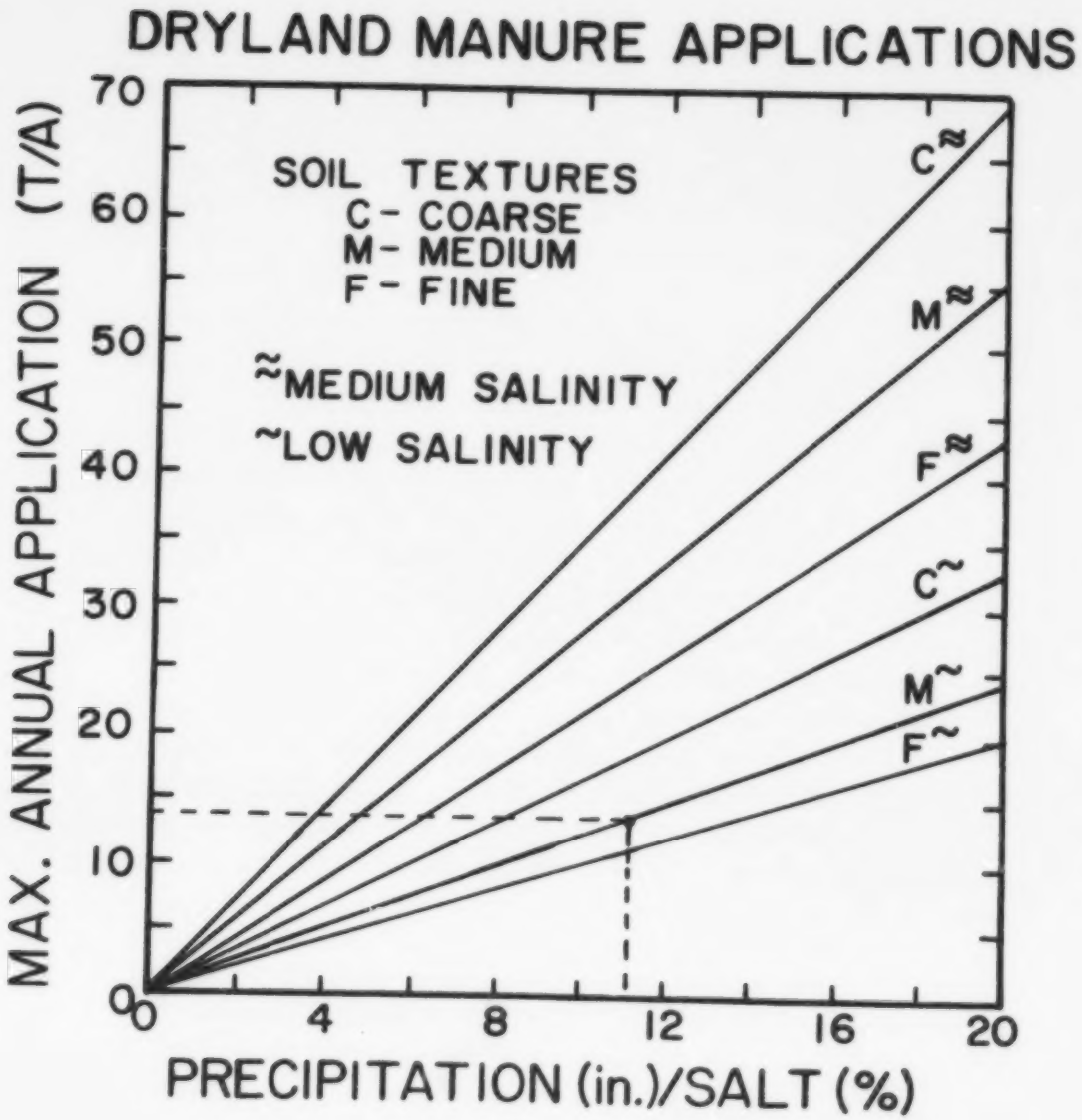

Figure 5. Annual application rates on nonirrigated land using air-dry manure.

this is less than our ratio of 0.65 established for medium textured soils and low salinity levels. Therefore, this application would not be expected to cause a dispersion hazard.

Summary of Calculation Procedure - In summary the following steps should be followed when applying beef cattle feedlot manure to soils of Western Kansas.

1. Decide on the crop to be grown, have a soil test performed, and estimate nitrogen losses to establish the amount of nitrogen ($N_c - N_s + N_L$) to apply.

2. Have the manure and irrigation water analyzed.

   a. Analyze the manure for percentages of nitrogen, phosphorus, potassium, sodium, calcium, magnesium, and moisture.

   b. Analyze the irrigation water for electrical conductivity and percent soluble sodium.

3. Determine the texture of the soil receiving the manure.

4. Use Equation (1) or Table 12 to determine the application rates R_J.

5. If the manure is applied to irrigated land determine the maximum annual application rate R_m from Figure 4.

6. If the manure is applied to nonirrigated land determine the maximum annual application rate R_m from Figure 5.

7. Compare the rate R_J from step 4 to the maximum allowable annual rate R_m in steps 5 and 6 to see if the planned rate will cause a salt build-up in the soil.

8. Calculate the dispersion hazard. If a hazard exists see your county agent.

9. Have annual salt alkali and soil fertility tests performed on the soil to check for possible salt build-up and nitrogen accumulation.

SECTION VIII

APPLICATION TECHNIQUES

The nitrogen fraction of animal waste should receive primary consideration when applying wastes to agricultural land. In the drier regions of the country the soluble salt fraction is also important. These two constituents are used as primary criteria for determining application rates and attempts to apply animal waste to land without this information is not likely to produce the desired results. The composition of the waste, therefore, must be determined by analysis.

Animal waste contains nitrogen, phosphorus, potassium, sodium, calcium and magnesium as well as a number of other elements of minor importance. Waste composition varies considerably from location to location as well as within a given stockpile at one location. The variability in composition is a result of different management systems, climate, animal species, and ration. If some soil is scraped from the lots along with the manure, the percent of each component will reflect that of the added soil. Waste taken directly to the field will have a higher nitrogen content than that which is stockpiled where leaching and decomposition can lower the nitrogen content. The concentration of soluble salts of potassium, sodium, magnesium and calcium depend on the type of ration being fed the animal. The concentration may be reduced in humid regions by leaching the salts from the manure.

Because of composition variability, animal waste should be analyzed for nitrogen, phosphorus, potassium, sodium, calcium and magnesium. Proper sampling of a stockpile is very essential. Several samples each from various locations and depths within the stockpile or a lot should be taken and mixed in a container. A sample from this mixture should then be analyzed and an average composition determined. It is desirable to take samples at two, three, or more different times during the year to further establish the average composition of the waste. Commercial testing laboratories are available for analyzing the waste. Animal waste analyses are usually expressed on a dry matter basis except sometimes in the case of slurries or liquids.

In order to calculate proper application rates several factors must be known. Among these are the soil type, nutrient needs of the crop, the nitrogen and salt contents of the waste, and the climate of the area. The nitrogen content of the material affects the rate at which the waste will decay; wastes with high nitrogen content decay faster. The nitrogen is mineralized only as the material decays so some of it is not released until the second, third or even fourth year after it is applied.

The salt concentration of the material is important in drier areas of the United States because excess salts in the soil can reduce plant growth. Because decomposition rates are affected by temperature and moisture, climate is an important factor. Climate is also an important factor in determining the amount of leaching from a given application site or from a given stockpile.

Because of the wide variability in soil type, fertilizer needs, and decay rates across the United States, it is difficult to give a universal formula for application rates. Some states have published guidelines for applying animal wastes. Among these are Indiana (30, 31, 32, 33), North Carolina (140, 141, 142, 143), Ohio (139), Maine (92), Oregon (225), Iowa (211), and Kansas (156, 157). We recommend that interested readers refer to these guidelines for their area. An example calculation based on Kansas guidelines is given in Section VII. If necessary, one should consult his county agent for recommended application rates. The safest application rates are the lowest rates which produce the best agronomic results, although some operations may wish to exceed these limits and use fields as disposal areas rather than using animal waste as a source of nutrients. Also some may wish to make large applications every few years rather than smaller applications each year. There is a potential hazard of salt build up in the soil and nitrate leaching following these large application rates. These practices cannot be recommended and if done, the soil and water in these areas should be monitored.

Proper and timely spreading and incorporation of a waste into the soil is important because it can prevent reduced crop yields and decrease the pollution potential. Spreading should be as uniform as possible to prevent local concentrations of ammonium and other inorganic salts which can

reduce germination and yields. Piles or windrows in the fields should be avoided. Sprinkler application of the liquid materials insures a uniform distribution, but gravity flow systems are workable. Incorporation immediately after application prevents rain and snowmelt from washing pollutants from the manure into streams, lakes, and domestic wells. This is of particular importance on sloping land. Application on frozen soil where manure cannot be incorporated is not recommended.

Lowered germination and reduced seedling growth could occur if planting takes place soon after application of animal waste (220). This toxicity is usually due to either increased soil salinity or high levels of ammonium nitrogen in the soil coming from organic matter breakdown. This problem can be reduced or eliminated by observing the following proper management practices: (1), apply the wastes well ahead of planting time; (2), do not apply excessive amounts of wastes to soils; and (3), pre-irrigate with good quality water, if available, before planting.

If animal wastes of low nitrogen content are applied, there is an additional reason for applying the waste well ahead of planting. If the waste has a low nitrogen content, there will be a period of several weeks when there is immobilization rather than mineralization of nitrogen in the soil. Ideally, planting should follow this immobilization so that mineralization is taking place at the time the crop starts to grow.

Ease of application depends to a great extent upon the physical condition of the waste. A friable material that has been allowed to decay and dry in a stockpile is much easier to load and spread than large chunks or a semi-solid material taken directly from the feeding area. However, some nitrogen and potassium can be lost from stockpiles by volatilization and leaching. Liquid material is best spread by irrigation systems or tank wagons with injection systems.

Land application can be beneficial to most crops. There are, however, some crops which are more readily adapted to waste application than others.

Silage crops such as forage corn and sorghum are best adapted for recycling nutrients because of their high dry matter yields which removes more nutrients from the application area. Avoid applications on sugar beets because release of nitrogen late in the season can lower sugar contents in beets. Also, manure application on soils planted to tobacco, tomatoes or oranges is not recommended. Annually cultivated crops are well adapted to waste application because of the ease in which waste can be incorporated.

SECTION IX

RESEARCH NEEDS

The ultimate objective of research is to discover the relationships needed for the development of application guidelines for animal waste application to land. Therefore the research needs mentioned here are those that will yield information needed to establish guidelines. These guidelines should establish application rates which maintain maximum productivity and nutrient recycling while avoiding increased soil salinity and contamination of surface water and groundwater. The plant uptake segment of the nitrogen cycle must remain efficient, since excess nitrogen could become a water pollutant.

In order to compare research results and to establish application rates, there must be a standardization of data. Analyses should always be expressed on a dry weight basis except possibly for liquids of low solids content (approximately 1% or lower). The location of the research should always be included when reporting data so that the climatic region can be determined. Soil characteristics which might influence application rate calculations should be given: slope, soil texture, presence of impervious layers in the profile, and depth to water table. With these standardizations, meaningful comparisons can be made and guidelines established.

In most regions of the United States nitrogen appears to be the best constituent upon which to base application rates. Although management practices and climate may determine the limiting constituent, other constituents such as salt build up in the soil, high copper and nitrate accumulation in plant tissues, or grass tetany in cattle may become the limiting constituent in some regions. In arid or semi-arid regions where lack of natural precipitation reduces leaching of salts out of the profile, the total inorganic salt content of the waste might become the limiting constituent. Studies on the mechanism of salt toxicity on plants is needed so that specific salts that cause the toxicity can be pinpointed.

There has been considerable information obtained on the characterization

of animal waste. From our review it appears that any differences in constituent concentrations due to climatic regions are overshadowed by the extreme variability of animal waste within a region. These differences preclude any use of an average value to establish application guidelines. Therefore, further information on characterization will do no more than verify the extreme variabilities that exist.

The variability of the composition of animal waste necessitates analysis of the waste before application. Sampling techniques and analytical procedures should be standardized so that errors in application rate calculations can be minimized. These standardized procedures need to be developed.

If nitrogen is to be used as a basis for establishing application rates, it is necessary to know the amount of nitrate nitrogen becoming available for plant uptake and movement with soil water. There are numerous published results on nitrogen transformation in soil and still numerous studies are underway. However, more information is needed on organic nitrogen decay rates. Experimental data must be gathered which can be used to determine nitrogen decay constants for different soil types, for wastes of different nitrogen contents, and for different climates.

Denitrification can affect determination of animal waste application rates. While it is recognized that this process can cause large losses of soil nitrogen into the atmosphere, little is known on how animal waste application affects this process. Such variables as soil texture, climate, and waste composition need to be examined as to how they affect denitrification. In some cases denitrification may account for large errors in underestimating the application rate of a given agronomic system.

Most data shows that if an animal waste is incorporated after application and soil erosion prevention is practiced, there is little loss of waste constituents into surface runoff. Some data has shown that surface runoff is reduced by waste applications because of increased infiltration rates associated with it. However, it needs further investigation because of its positive aspect of land application. More long-term experiments are needed to study the effects of various application rates on crop yields,

nutrient availability, and soil salinity. Only by continuing experiments on a long-term basis can the validity of application rate guidelines be evaluated.

SECTION IX

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SECTION XI

LIST OF PUBLICATIONS

Wallingford, G. W., W. L. Powers, and L. S. Murphy. Present knowledge on the effects of land application of animal waste. To be presented at the International Symposium on Livestock Waste, April 21-24, 1975, at the University of Illinois, Urbana-Champaign.

SECTION XI

GLOSSARY

Algal bloom - The growth of algae on streams or lakes usually caused by excess nutrients in the water.

Beef runoff - Runoff from beef feedlots caused by precipitation or melting snow.

BOD_5- Biological oxygen demand. The quantity of oxygen used in five days in the biochemical oxidation of organic matter.

Bulk density - Density of the soil expressed as the dry weight per unit volume.

CEC - Cation exchange capacity. The capacity of the soil to attract and hold cations, usually in terms of millequivalents per hundred grams.

COD - Chemical oxygen demand. The quantity of oxygen used in the chemical oxidation of organic matter.

Colloid - Small individual particles of soil, very small in size.

Decay rate - The rate at which organic material decays.

Decay rate constant - The fraction of the remaining material which decays.

Denitrification - The process by which nitrate is converted either to nitrogen, nitrous oxide, or other gases, usually under anaerobic conditions.

Digested slurry - That slurry which was intentionally subjected to digestion such as aeration or anaerobic treatment and material removed from this digestion system in a scheduled manner.

Grass tetany - A disease of animals thought caused by an imbalance between magnesium and potassium in the feedstuff.

Heavy metals - Those metals such as copper, lead, zinc, iron, cadmium, and nickel.

Hydraulic conductivity - The ease with which water will be transmitted through a soil.

Infiltration rate - The rate at which water will enter a soil.

Inorganic salts - Those salts of the inorganic cations calcium, sodium, potassium, and magnesium and of the inorganic anions chloride, carbonate, and sulfate.

Leaching - The movement of materials such as calcium, magnesium, sodium, nitrate, or chloride through the soil with water.

Micronutrients - Nutrients needed in small amounts.

Microorganisms - Bacteria or small organisms.

Mineralization - The process by which organic compounds are converted to inorganic compounds, such as the conversion of organic nitrogen into nitrate nitrogen.

Nitrification - The formation of nitrate from the decay of organic nitrogen or from the biochemical change of ammonia to nitrate.

Nutrients - A compound or element needed by plant or animal for metabolism and growth.

Percolation - The process of water moving downward through the soil profile.

pH - A measure of the hydrogen ion concentration.

Pore space - That area between the aggregates or individual soil particles which can contain either air or water.

Saline soil - One which is high in inorganic salts; one which has an electrical conductivity of the water-saturated-parts extract of 4 millimhos/cm or greater.

Soil aggregates - Those particle in the soil formed by various arrangements of sand, silt, clay, and organic matter.

Soil horizon - The horizontal layers in a soil profile.

Soil microbes - Microorganisms which live in the soil.

Soil texture - The percent sand, silt, and clay in the soil.

Solid manure - That manure in the solid form which cannot be pumped through pipelines.

TOC - Total organic carbon.

Undigested slurry - A liquid mixture of manure that has not been digested through intentional means.

Volatilization - The process by which materials are converted to vapor.